Industrial Waste Streams

Although papermaking and crop agriculture might seem at first to be the whole world of Wisconsin's existing bioindustry, there are many major state industries with organic feedstocks and waste streams, including breweries, dairies and cheese plants, meat processing, and fruit and vegetable processors, as well as municipal waste. We also consider paper mill residue as a feedstock distinct from the ideas presented in the Forest Biorefinery channel. These industries combine urban and rural resources in a way that challenges existing ideas about biorefineries. Furthermore, biorefining is, when considering resource utilization, an example of best practices, meaning that to succeed is to operate leaner than unintegrated competitors.

Channel Summary

The sheer breadth of biomass available in industrial waste streams means that the opportunities in this channel will not tidily reduce into any one direction. There are few opportunities in the sector on the scale of Anamax's 20 million-gallon biodiesel plant, which is a natural complement to their grease collection business. (See case study later in this channel.) Many industrial producers will find the most compelling business case in working with other regional biomass producers to combine their feedstocks, such as the use of municipal POTWs to digest industrial waste.

Opportunities

- Industrial waste streams will most commonly be supplements to other biorefining processes, as opposed to resources that naturally suggest on-site handling.
- Biomass in question is by and large not being utilized whatsoever, and often requires payments for disposal.
- Oversized municipal POTWs could be an easy "win" for digesting regional biomass and should be investigated.

Hurdles

- Potential feedstock disposal costs and risks are shared while biorefining costs and risks would not be.
- Partnerships necessary for successful biorefining operations, including public/private, are not established.
- Difficult to value the contribution of each feedstock to a biorefining process, especially in cases where it displaces a disposal cost.
- Only large industrial waste streams currently support on-site biorefining operations.
- Success can drive competition for the resource, which we have already seen with waste cooking oil.
- Waste streams are not always "taken seriously" by business, reducing engagement and enthusiasm for these projects.
- Production of biogas for onsite use is an easy win.
- Paybacks are often too long for industries to fully investigate.

- Technologies often need to be customized and integrated for specialized processes.
- POTWs with spare capacity can thwart opportunities through rate increases.

Biorefining Opportunity

The opportunities in the industrial sector are overwhelmingly focused on waste streams, for the simple reason that these coproducts almost always pose a disposal cost to the businesses that generate them. The ability to avoid that cost, or even to add enough value to these coproducts such that they generate revenue, provides a unique incentive for industrial-scale biorefining when compared to exploring new uses for resources with established valuable uses.

Ecological business models, where the waste stream of one operation is the input of another, are steadily gaining in popularity (at least conceptually). However, identifying and exploiting these opportunities is difficult and frequently requires commitment and creativity from multiple organizations. Additionally, waste stream management, like human resource management, is an ancillary activity, and while these activities can impact value they are rarely, if ever, the main drivers. As such, it can be difficult to make a case for innovation or taking on additional risk in waste stream management.

On the plus side, these attributes create a range of opportunities to facilitate and encourage adoption of beneficial waste stream management practices.

Channel Resources

As stated above, the primary resources for the industrial waste streams channel come from Wisconsin's food processing operations, including: fruit, vegetable, meat and dairy processing and brewing. The overwhelming majority of these waste streams are in the form of wastewater; however, solid wastes represent an important component as well. Solid wastes include spent grains from brewing, whey, pomace, scraps and spoilage from fruit, vegetable and meat processing.

Food processing wastewater streams are typically evaluated on the basis of biochemical oxygen demand (BOD). A high BOD indicates that the water contains high levels of dissolved or suspended solids, minerals and organic nutrients containing nitrogen and phosphorus.[1]

The BOD level from a typical residence is around 250mg/L.[2] BOD levels from food processing plants vary widely but typical values include several thousand mg/L. Dairy and meat processing plants in particular can have very high BOD levels due to high concentrations of milk and blood in the wastewater.

Food processing wastewater is typically considered nontoxic under the EPA's Toxic Release Inventory and can therefore be treated by conventional biological technologies.

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[1] http://www.p2pays.org/ref/09/08853.htm
[2] http://www.cet.nau.edu/Projects/WDP/resources/Characteristics.htm

However, the combination of high volumes and high BOD levels can quickly overwhelm a small, rural publicly-owned treatment works (POTW), and even if the POTW is sized to handle the waste streams, the cost to the processor can be high since additional charges will typically be applied to wastewater with BOD levels above 250-300mg/L.[3]

Fruit and Vegetable Processing

Wisconsin is home to approximately 75 facilities which process snap beans, sweet corn, peas, potatoes, cabbage, cucumbers, cranberries, cherries, apples and other fruits and vegetables.[4] These processing facilities are typically located close to the agricultural producing regions in order to reduce shipping costs and the risk of product spoilage.

Fruit and vegetable processing wastewaters are high in suspended organics but residual pesticides are also a concern. Preprocessing techniques have been used to reduce the amount of material lost to waste streams and advances have been made in degradation processes for reducing pesticide concentrations and toxicity.[5]

The primary steps in processing fruits and vegetables include general cleaning and dirt removal; removal of leaves, skin and seeds; blanching; washing and cooling; packaging; and cleanup.[6] Significant amounts of water are used in the washing, cooling and cleanup steps. Processing a ton of fruit or vegetables can consume anywhere from 960-8400 gallons of water depending on the product and the process used.[7]

Meat Processing

Wisconsin has 284 state-licensed meat processing facilities which handle cows, calves, hogs, chickens, turkeys, ducks and fish.[8] The waste streams from these facilities include wastewater and inedible animal parts. The inedible animal parts are typically collected as solid wastes and are most often converted into products rather than being disposed. These products include animal feed, fertilizer and cosmetics feedstocks. In addition to BOD, pathogenic organisms are a significant concern in meat processing wastewaters. In general, meat processing is the most closely monitored of the food processing industries, including minimum water use requirements in poultry cleaning procedures.[9]

Meat processing can be generally broken into the following basic steps: rendering and bleeding; scalding and/or skin removal; internal organ evisceration; washing; chilling and cooling; packaging; and cleanup.[10] Bleeding, washing, chilling, cooling and cleanup all use significant amounts of water and processing one ton of meat typically requires 3,600 to 4,800 gallons of water.[11]

Dairy

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3 http://www.p2pays.org/ref/09/08853.htm (repeat reference)
4 http://www.dnr.state.wi.us/org/caer/cea/assistance/foodprocessing/info.htm#Fruits
5 http://www.p2pays.org/ref/09/08853.htm (repeat reference)
6 http://www.p2pays.org/ref/09/08853.htm (repeat reference)
7 Metcalf and Eddy, Wastewater Engineering: Treatment, Disposal and Reuse, 3rd Edition, 1991
8 http://www.dnr.state.wi.us/org/caer/cea/assistance/foodprocessing/info.htm#meat (repeat reference)
9 http://www.p2pays.org/ref/09/08853.htm (repeat reference)
10 http://www.p2pays.org/ref/09/08853.htm (repeat reference)
11 Metcalf and Eddy, Wastewater Engineering: Treatment, Disposal and Reuse, 3rd Edition, 1991 (repeat)

The Wisconsin dairy industry includes over 350 state licensed plants that process milk.[12] The dairy industry can be split into fluid milk and processed milk products. Processed milk products include cheese, butter, ice cream, dried milk and whey. Overall, the dairy industry is fairly static with growth in yogurt and ice cream production being offset by declines in liquid milk and butter.[13]

Milk processing typically consists of the following steps: clarification or filtration; blending and mixing; pasteurization and homogenization; product manufacturing; packaging; and cleanup. The majority of wastewater from the dairy industry comes from the start-up and shut-down of high-temperature, short-time pasteurization which contains high concentrations of pure milk in water. The second major wastewater source comes from equipment and tank cleaning. These cleaning streams include cleaning agents in addition to milk and water. Dairy processing typically requires between 2,400 and 4,800 gallons of water per ton of product[14] but roughly 90 percent of dairy wastewater is milk.[15]

Brewing
Wisconsin is home to over 80 breweries[16] of various sizes, the largest by far being Miller Brewing Co. in Milwaukee (see sidebar). Location of breweries is typically not geographically tied to raw material or feedstock production. Water, population density and access to rail and interstate trucking are more important factors. Overall water usage for breweries is comparable to other food processing facilities but BOD concentrations are typically significantly higher with values as high as 12,000mg/L reported for some facilities.[17,18] Solid wastes are typically captured and sold as animal feed.

Brewing typically consists of the following processing steps: raw material handling and processing; mixing, fermentation and/or cooking; cooling; bottling and packaging; and cleanup.[19]

It is important to note that a brewery’s relationship to its municipal wastewater systems can become entrenched, mitigating in some ways the driver of the disposal fee. Miller Brewing operates anaerobic digesters for its wastewater at all of its plants except Milwaukee, for reasons beyond just offsetting gas purchases. “The other incentive at the other plants are the high wastewater treatment costs,” said James Surfus, Senior Environmental Engineer for Miller. “We are blessed with reasonable costs here in Milwaukee.”[20]

Municipal waste streams

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[12] http://www.dnr.state.wi.us/org/caer/cea/assistance/foodprocessing/info.htm#dairy
[13] http://www.p2pays.org/ref/09/08853.htm (repeat reference)
[14] Metcalf and Eddy, Wastewater Engineering: Treatment, Disposal and Reuse, 3rd Edition, 1991 (repeat)
[15] http://www.p2pays.org/ref/09/08853.htm (repeat reference)
[16] http://nowgohaveabeer.tripod.com/brewers.htm
[17] http://www.p2pays.org/ref/09/08853.htm (repeat reference)
[18] http://www.wrc.org.za/downloads/watersa/2005/Jan-05/1720.pdf
[19] http://www.p2pays.org/ref/09/08853.htm (repeat reference)
[20] Personal communication with James Surfus. 2 December 2005.

Of the 4.75 million tons of municipal solid waste generated annually in Wisconsin, more than half is organic matter.[21] Collection occurs throughout the state. Municipal wastewater in Wisconsin is handled in one of more than 100 facilities, approximately 85 of which use anaerobic digestion.[22]

Paper mill residue
Wisconsin pulp and paper mills annually produce 1.7 million wet tons of residue.[23] While each mill's residue has unique components, this residue is on average 50 percent solid, and of these solids, roughly 50 percent is woody fiber and the other 50 percent is inorganic matter such as clay.

Market Considerations

The majority of initiatives dealing with waste stream management in the food processing industry emphasize reduction of generated wastes. This makes sense in several ways, the first being that for many operations, most notably dairy, the waste streams represent wasted salable product. Secondly, reducing waste volume and/or concentration is frequently the most cost effective means of addressing disposal costs. Once these improvements have been made (or where they are impractical, as with blood cleanup) advanced treatment options may be the next step.

There are a number of ways that advanced industrial waste stream management can be encouraged. Probably the single most important aspect of enabling these changes will be to bring all the participants together for information exchange. This means bringing together the waste generators, the process technologists and those who could potentially utilize the process outputs. At this point, there will presumably be an available resource and a potential application, also known as supply and demand. However, there is no guarantee that the transaction will take place.

Another important step, once opportunities have been identified, is risk mitigation. This can take many forms including feasibility studies, technical assistance or financial assistance—either in the form of advice or money.

PEST Analysis

Key issues facing the biorefining of industrial waste streams include the incredible institutional inertia that is ever-present when attempting to change any aspect of an industrial process, especially something as overlooked (and therefore more entrenched) as waste streams. The need for intricate public/private and private/private partnerships for processes that often require consistency but rely on outputs whose production is not optimized is a formidable hurdle.

Political/Legal

[21] http://wisbiorefine.org/feed/munisolidwaste.pdf
[22] Vik, Thomas E. 2003. Anaerobic Digester Methane to Energy: A Statewide Assessment. Focus on Energy. Neenah, Wis.
[23] http://wisbiorefine.org/feed/papermillresidue.pdf

- + Bioremediation is a beneficial and often revenue-positive solution to disposal problems.
- + These technologies can mitigate other undesirable qualities such as odor.
- + State, local and water quality initiatives are all particularly strong technology-adoption drivers in this channel.
- ± For wastewater, many of these solutions will impact discharge permits.
- ± POTW relationships must be negotiated when processing affects wastewater flows.

Economic

- + Point sources of waste provide a first level of collection infrastructure.
- + These technologies allow industry to reduce their waste disposal costs, either through their own adoption of the technologies or their relationship with someone who wants to process their biomass.
- – Justification often requires sophisticated cost/benefit analysis.
- – Some waste streams are seasonal.

Social

- + Environmental benefits accrue from advanced waste management.
- + Businesses' general indifference toward waste creates an opportunity for entrepreneurship.
- ± The public/private partnerships required for projects like the digestion of industrial waste at a POTW do not currently exist.
- – The industrial community at large is not sufficiently knowledgeable to identify and exploit opportunities.
- – The bioeconomy's emphasis on waste stream processing is at odds with the environmental community's emphasis on prevention of waste.

Technological

- + Many of the technologies to be applied to these feedstocks are established.
- ± Anaerobic digestion dominates how this resource is currently handled.
- – High moisture content of the waste streams limits their handling options.
- – The biomass must be stored. In a regional digestion scenario, it must be stored both on-site and at the digester.
- – Most technologies in this channel require customization, integration into existing infrastructure and, in some cases, experience not readily available in the state.

The diverse nature of the feedstock and the even more diverse nature of feedstock suppliers make this a tricky sea to navigate. For regional processing to succeed, much work will need to be done to negotiate the public/private and private/private partnerships that would underpin it.

Technologies

Unlike the other channels, the industrial feedstocks are sufficiently diverse that it is difficult to talk generally about technologies without isolating which specific biomass sources are being discussed. The following technologies have been identified as being relevant to the selected associated feedstocks:

- Anaerobic digestion
  - Municipal biosolids
  - Pomace, scraps, spoilage and fruit & vegetable processing wastewater
  - Scrap, spoilage, offal and meat processing wastewater
  - Whey and dairy wastewater
- Biomass gasification
  - Municipal solid waste
- Combustion
  - Municipal solid waste
- Fiber composites manufacturing
  - Paper mill residue
- Transesterification
  - Scrap, spoilage and offal
  - Waste cooking oil

Anaerobic digestion

- Municipal biosolids
- Pomace, scraps, spoilage and fruit & vegetable processing wastewater
- Scrap, spoilage, offal and meat processing wastewater
- Whey and dairy wastewater

Digestion of municipal biosolids already happens throughout the state, and while these digestion operations are typically oversized enough to permit codigestion with other feedstocks, the municipalities are understandably wary—while digestion permits the coprocessing of multiple feedstocks, the bacterial culture that does the digesting is tuned for certain feedstock characteristics, and if the supplemental inputs are not consistently available, their inclusion may be more logistical trouble than they are worth. For digesters that solve this problem, however, the inclusion of supplements such as whey can increase biogas yields significantly. The flipside of

A NEW APPROACH TO AD

Ecovation, based in Victor, NY, builds customized anaerobic digestion systems for removing organic solids from high-strength wastewater streams. Using its patented “ultra high-rate” treatment process, the company provides customized wastewater treatment solutions built on standard modules of its Mobilized Film Technology digesters.

Ecovation has even built a test and demonstration lab at its headquarters so that treatment parameters can be developed ahead of time and customers can actually observe the technology, which is conceptually similar to a fluidized bed process, at work through specially designed glass-walled reactors. This is a high level of customer service in any industry, but Ecovation goes further, performing system design, construction, commissioning and, if the customer chooses, maintenance and operating of the system either directly or through a subcontractor.

Ecovation is an example of a company which has identified a niche it can serve quite well with its proprietary technology. The company’s success is based on its ability to identify projects within this niche and stay focused on serving those customers more effectively than any other solution provider can. The Ecovation web site states, “Our team of experts is skilled in assessing the applicability of our technology to individual waste streams. Current and potential clients find this an invaluable time, energy and cost savings process.”

the issue is that the inclusion of municipal biosolids in a digester severely limits the application of the solid and liquid products of digestion. As the markets for these products develop, it may be that non-municipal producers would do better to perform their own digestion without the contamination of human waste.

A 2003 study commissioned by Focus on Energy suggests that municipal wastewater digestion alone could generate 2.3MW at the 23 largest sites in the state.[24]

[24] Vik, Thomas E. 2003. Anaerobic Digester Methane to Energy: A Statewide Assessment. Focus on Energy. Neenah, Wis.

Table 1: SWOT analysis of industrial waste streams via anaerobic digestion

	Positive	Negative
Internal	*Strengths* • Established technology • Can process multiple feedstocks • Can process high H_2O wastes • Controls odor • Minimal intellectual property issues (lots of vendors) • Reduces GHG emissions • Lower emissions than combustion • Provides additional revenue streams • Industrial scale allows consideration of more complex systems • Reduces BOD levels in wastes	*Weaknesses* • Large scale required • Lack of standardization of technology • Uses biological process that can be upset • On-site waste management increases management burden and labor costs • Limited markets for products • Product sales need specialized agreements or technology (PPA, grid interconnection, gas cleaning) • Existing AD units must have spare capacity for co-digestion of multiple feedstocks • Permitting requirements can be a barrier to adoption • Waste treatment traditionally viewed for cost containment rather than revenue generation • Biogas may need cleanup

	Positive	Negative
External	*Opportunities* • Ongoing efforts are likely to reduce minimum scale, identify better bacteria or microbes and improve basic reactor design • New business models being develop to reduce risk and address O&M • Allows displacement of fossil fuels • Further processing of solids • Potential to expand existing capacity • Many municipal systems are oversized but not setup to do AD • May allow for co-digestion of other local wastes • Opportunity for on-site ammonia production • Avoided tipping fees • Demonstrated cost neutral to slightly positive cash flow for waste water treatment	*Threats* • Limited applications if municipal biosolids are co-processed • Perceived regulatory barriers/pushback, especially for co-processing

Anaerobic digestion is a proven, reliable way to extract energy and value from waste streams and in particular from multiple waste streams simultaneously. Regional facilities, including POTWs, offer an immediate opportunity to begin to forge relationships between diverse feedstock suppliers.

INDUSTRIAL WASTES AT MILWAUKEE MUNI ANAEROBIC DIGESTER

In an attempt to boost energy production at a municipal anaerobic digester, the Milwaukee Metropolitan Sewage District recently worked with Dan Zitomer and Prasoon Adhikari of Marquette University to conduct a feasibility study at its South Shore Wastewater Treatment Plant (SSWWTP) in which the plant received food processing wastes, including beer filter waste from Miller Brewing Co., food waste from Pandl's Restaurant, and fermentation byproducts from Lesaffre Yeast and Southeastern Wisconsin Products. Each wastestream did, for a certain range of concentrations, increase biogas production at the plant, with the fermentation waste having an unexpected synergistic effect out of proportion to the additional COD it represented. (Zitomer hypothesizes that the bioavailable nutrients in the waste, such as iron, spurred microbial growth.) The addition of the beer filter waste was less impressive, and while it was successfully digested, it may not be economical for the purpose of boosting gas production. The restaurant waste was sufficient to offset enough natural gas for approximately three homes—an idea that becomes attractive when considering a network of restaurants all submitting their waste to be digested.

For as much as this seems like an obvious win, in that the digester is currently operating with sufficient excess capacity to take on these wastes and that this model must be replicable elsewhere, there are significant infrastructure hurdles to overcome. The food waste was treated using the Rothenburg Wet Waste Recovery System distributed in the US by Ecology LLC of Glendale, Wis., which converts the food waste to a slurry to be stored on-site until pick-up. Likewise, additional storage facilities are needed at the POTW, as well as mixing facilities, tanker trucks and other infrastructure necessary for full-scale operation. Also, while a digester can handle all of these wastes, digesters tend to be tuned to handle a certain composition of feedstock, and significant variability in that feedstock can negatively impact performance, requiring a reliable supply of these wastestreams. Nevertheless, the study suggests that this approach to industrial co-digestion is more than feasible and deserves further attention.

http://www.focusonenergy.com/data/common/dmsFiles/W_RB_RPTE_MarquetteUnivFeasStudy.doc

Biomass gasification

- Municipal solid waste

The drawbacks of gasification—namely, the large sizes (and, accordingly, feedstock volumes) that the technology favors and the limited value of the products of the process, which again favors large-scale operations and co-location with another large facility that can exploit all of the heat and power produced—apply as much here as anywhere. In urban industrial settings, however, gasification may be prized for its cleaner emissions relative to combustion, which can help put a price to that externality that justifies the expense of gasification.

Table 2: SWOT analysis of industrial waste streams via biomass gasification

	Positive	Negative
Internal	*Strengths* • Established technology with multiple vendors • Fewer emissions than combustion • Converts waste to fuel • Feedstocks already gathered • Allows use of multiple feedstocks, including inorganic • Process is technologically scalable • After cleaning, syngas works in existing natural gas applications • Syngas can be stored for later use to follow loads	*Weaknesses* • Presently not cost competitive with combustion except in niche applications with environmental issues • Feedstock must be dry and pulverized – industrial waste streams tend to be high moisture content • External market for syngas undeveloped • Syngas needs cleaning before use in power generation • Economies of scale and automation favor large operations
External	*Opportunities* • Renewable fuel that competes directly with natural gas • Can combine with other feedstocks • Syngas may be developed as a chemical feedstock • UW research strengths on catalysis align with US DOE priorities	*Threats* • Vulnerable in case of a price drop for natural gas or natural gas substitute • US DOE has discontinued R&D for small scale applications

Gasification is an extremely promising technology, but one for a time in which its emissions profile is properly valued. In an industrial setting, the ability to gasify some inorganic materials along with organic ones (see case study below) helps the business case for adoption.

WOOD FLOUR, CARPET WASTE GASIFIED FOR $2.5M ANNUAL SAVINGS

Shaw Industries' Plant 81 in Dalton, Ga. has embarked on an innovative and ambitious project to convert carpet and wood manufacturing waste to steam energy via gasification. The results of this venture will reduce manufacturing byproducts destined for the landfill, produce lower plant emissions, and eventually save up to $2.5 million per year.

Gary Nichols, the Shaw energy manager who heads up the project, reports that the concept for the project has been in the works for more than three years. "This is really a bold undertaking for the company," he says. "We've never done anything like this before, although it is something we have been considering for a long time. In the past three to four years energy costs and technology have come together at the right time to make this a viable project."

In the conversion process, manufacturing carpet waste and post-consumer carpet waste, as well as wood flour (dust generated from trimming during manufacturing), are turned into steam which will be used to power the operations of Plant 81. The facility is projected to be fully operational by the end of 2005. Barron says the project is estimated to convert approximately 15,000 tons of postindustrial carpet waste, 1000 tons of post-consumer carpet waste, and 6,000 tons of wood flour per year.

Developed in cooperation with Siemens Building Technologies, the gasification facility will be adjacent to the manufacturing plant and supervised by Shaw personnel. "This represents a huge savings in terms of landfill reduction and energy costs," said Nichols. "In addition, this initiative is extremely environmentally friendly in the cleaner emissions that will result, particularly the tremendous reduction in sulfur dioxide." Carpet and wood wastes burn cleaner than coal, without the heavy metals present in natural coal deposits (supported by ongoing studies conducted by Georgia Tech and the EPA).

The company is studying ways to use the remaining waste by-products, such as filler, that result from the conversion process. Carpet salvage and seam waste are baled and sent to a grinder to separate the fiber from the filler, and the fiber is used in the gasification process. Another by-product is the ash produced through gasification. Nichols and his team are optimistic they will find a use for these materials in other manufacturing operations.

Combustion

- Municipal solid waste

Burning garbage has always been regarded dubiously, but changes in technology combine with combustion's status as a "starter" biorefining process to make this intriguing. Burning waste wood has long been favored as a means of local heat and power generation by forest-oriented industries. However, as is the case with many of these technologies as they apply to the industrial sector, it makes the most sense when you consider the industrial waste streams to be a supplement to another, equally large or larger feedstock stream.

Table 3: SWOT analysis of industrial waste streams via combustion

	Positive	Negative
Internal	*Strengths* • Established technology • Feedstock quality is not essential • Cheap way of reducing volume for disposal • Derive energy from wastes • Feedstocks are currently concentrated	*Weaknesses* • Low value use of feedstock • Limited products (heat, power, ash) • Should have use for products on site • Potential for air emissions issues • Not appropriate for large-scale uses • Economic distance from which to draw feedstocks is limited by low value • Efficiency is often poor because feedstocks typically are high moisture • Contaminants in ash may make disposal a problem
External	*Opportunities* • Can serve many small end uses • Allows displacement of fossil fuels • May be a stepping stone technology for aggregation of feedstocks • Opportunity for co-firing • Useful at the end of the biorefinery value chain	*Threats* • Economics depend on price of competitor fuels (natural gas, propane) • Widespread adoption in use could create air pollution issues • Disposal-oriented combustion typically not tuned for efficient energy production (e.g. recovery boiler)

Combustion is the simplest form of biorefining, but process heat is always useful, and combustion projects can promote the collection of otherwise uncared-for biomass. Emissions issues will always be front and center as these installations are considered.

Fiber composite manufacturing

- Paper mill residue

Fiber composites are an interesting application for a waste stream in that they embrace the uniqueness of the resource—that is, the strength and durability of the fiber—where most processes are looking for interesting ways to disassemble the biomass into desirable components. But capturing that value when the feedstocks are contaminated presents its own challenge. When dealing with paper mill residue, the composite product will be a fiber/cement composite wherein the fibers serve as aggregate in a cement-based product.

Table 4: SWOT analysis of paper mill sludge via fiber composites manufacturing

	Positive	Negative
Internal	*Strengths* • High bulk density • Large quantities are available in single locations • Relatively easy to handle	*Weaknesses* • Widely variable quality due to day-to-day changes in what is being pulped • High inorganic component (clay and other fillers), often 50% or more • Short fibers • High water content, typically >50%
External	*Opportunities* • Avoidance of landfill fees • Landspreading (aka: soil amendment) opportunities are declining • Cheap filler for low quality fiber/cement composites	*Threats* • Other low quality filler materials (like sand) readily available and more consistent • Not worth hauling

Paper mill residue may find beneficial reuse in cementitious products, but this is something that will only happen because an entrepreneur has a preferred process and pursues the feedstock. R&D along those lines is being performed today.[25]

[25] http://www.nrri.umn.edu/default/nrri.asp?pageID=50

Transesterification

- Scrap, spoilage and offal
- Waste cooking oil

This is a curious exception to the expected slow adoption of biorefining technologies in that it has begun to proliferate at the garage scale while industry works to get up to speed. New technologies allow these feedstocks to be confidently coprocessed with virgin plant oils.

CUTTING-EDGE BIODIESEL IN WIS.

When Anamax opens their 20 million gallon biodiesel facility in DeForest in early 2006, it is expected to not only be the second largest in the nation, but one of the most technologically innovative. Where the traditional biodiesel plant relies on batch processing of single feedstocks and water washing to isolate the biodiesel, the DeForest plant is a continuous-flow, multi-feedstock, distillation-oriented facility capable of making ASTM-friendlier clear biodiesel and 95% pure glycerin. What's more, they expect to make biodiesel for only 35-40¢/gal on top of feedstock costs, which is roughly half of the "traditional" cost. They won't be the first to use this technology—a plant in Iowa will beat them by a few months—but they'll be the first to take advantage of its ability to process multiple feedstocks.

Anamax has known it wanted to do this for some time, to the point of installing a rail spur three years ago and, at the same time, investing in R&D for the uncommercialized technology that drives their plant. They wanted to fully commit to the plant, but the question was when. "When they signed [the Energy Bill] in January, that's when the decision was made," Anamax Grease Services general manager Mike Spahn said, referring to the 50¢-$1/gal incentives that the Energy Bill put into place for the next three years. Although those tax breaks go the blender, they let suppliers negotiate for better prices. "That was really what was needed to get the ball rolling. Of course, high fuel prices got us rolling again, too—had we gotten this plant up and running a year or two, we would be feeling pretty good right now." Spahn expects oil prices could drop as low as $40/barrel before he'd start "getting concerned."

Although the DeForest facility has been collecting industrial grease waste for more than 50 years, this will not be their primary feedstock for the biodiesel operation. “We have a current customer base that we want to continue to supply, which means that takes all the production that we currently have here, which then means we need to purchase 20 million gallons of oil on the open market,” Spahn said. He expects to transition to making biodiesel from yellow grease when its demand prices it out of the animal feed market.

The plant will not be using Wisconsin feedstocks when it opens. While Wisconsin’s soybeans would be a natural source for the oil Anamax intends to purchase, there is no soybean crushing operation in southern Wisconsin, although Spahn said the announcement of their biodiesel has spurred interest in developing one. If soybeans from Wisconsin happen to be used when the plant opens, it will only be after Anamax has paid someone out-of-state for the added value of oil production. Likewise, National Biofuels of Texas has a contract for 100% of the biodiesel the plant produces, and while it may end up in area pumps, the blending will not necessarily take place in Wisconsin. The technology in which Anamax invested is also from out-of-state: Biosource Fuels of Montana. The primary economic development that will come from the plant is the 10 to 15 people it will employ. For Wisconsin to reap as much benefit as it could from the opportunity the Anamax plant presents, it would need to have businesses that could compete in each of these arenas.

The main byproduct of biodiesel production is glycerin. Anamax is aware of glycerin’s potential for fuel cells and is in talks with Virent, a Wisconsin company with a process to turn aqueous sugar feedstocks like glycerin into hydrogen, but Spahn sees his plant’s principal opportunity at this point in the paintball market: Paintball manufacturers using his high-purity glycerin don’t require as much costly dye because the glycerin is so clear.

Table 5: SWOT analysis of industrial waste streams via transesterification

	Positive	Negative
Internal	*Strengths* • Established technology • Standard exists for biodiesel quality • Fits within existing infrastructure • Process is scalable over a broad range • Existing collection infrastructure	*Weaknesses* • Market for and disposal of byproducts is currently limited • Questions exist on vehicle warrantee impacts of biodiesel use • May require significant filtering and preprocessing to be useable
External	Opportunities • Existing markets for biodiesel • Allows displacement of fossil fuels • Upcoming federal changes to diesel fuel formulation (sulfur content) • Glycerin production can support other biobased products • Potential user of biobased methanol • Can mix with other lipid products • Value added opportunity for waste oil/fat haulers and slaughtering operations	Threats • Economics depend on prices of substitute • New catalytic conversion processes may make transesterification obsolete

Production of biodiesel from waste oils and greases is very promising, especially as the market matures. Much of the state's collection is handled by Anamax, who is building a biodiesel facility; this presents feedstock and scale challenges to others in the state interested in the same technology. Beneficial use of glycerin is a major issue.

Context within Integrated Biorefinery

Industrial waste streams are the ultimate supplement to a biorefinery—in many cases, the waste stream producers consider the waste stream a problem rather than an opportunity and are happy simply to avoid disposal costs. For industries that choose to be proactive about their waste streams, an on-site facility can significantly reduce the need for heat and/or power, and, if designed properly, can be the aggregation point for other local waste streams that will only enhance those benefits.

Table 6: Industrial Waste Streams Channel Timeline

Immediate	Near Term (1-5 Years)	Future (Beyond 5 years)
Scoping, development of infrastructure for digestion of industrial wastes at POTWs	Established collection, storage services coordinated with POTWs and other regional digesters as viable alternative to other forms of disposal for many businesses	Formal market for biological coproducts based on their ability to boost digester gas output; regional digester model proven and being emulated
Garage-scale production of biodiesel from waste grease	Transition large-scale biodiesel plants from plant oil to waste grease	Economics, technology may permit less centralized biodiesel production
	Combustion of waste biomass justifies solution to logistical issues of collection	With logistics solved, advanced procession of waste biomass such as gasification implemented

New and Dedicated Crops

New and dedicated crops pose a potentially significant, but unknown opportunity for Wisconsin. These crops include existing crops that could expand production or new crops that offer high-value uses. They include transgenic crops that are themselves biorefineries that produce value-added chemicals or enzymes. While the potential is significant, the challenges to expanding the use of new or dedicated crops are equally significant.

Channel Summary

The University of Wisconsin has done extensive research on potential new uses for crops and new crops. Primary candidates for this area are potatoes and alfalfa, and the University of Wisconsin has intellectual property ownership for both. However, the complexities of intellectual property prevent the commercialization of these technologies. We illustrate this complexity in the case study of the University of Wisconsin's phytase experience (see below).

The barriers are varied. Intellectual property issues may limit the expansion. In other cases, the crop support system is biased toward corn and soybeans, effectively disincenting farmers from growing other crops. Past history of new and highly touted crops, such as Jerusalem artichokes (see case study below), makes individuals in the farming community loath to be the first to try new crops in significant amounts. The markets for the products or services the crops can provide sometimes do not exist. New and dedicated crops demonstrate quite clearly the distance between potential and marketplace success.

The ultimate potential is unknown. However, existing research has shown that crops can be designed for enzyme production and potentially for many other high value uses. Wisconsin can capitalize in this channel in two areas:

- Development of *commercializable* intellectual property, and
- Implementation of the crops

The first option, the development of intellectual property, illustrates a key university/private industry partnership opportunity. Careful attention must be paid to the intellectual property issues surrounding an innovation. The role for research in this market is less focused on "pure" research and more focused on specific commercial outcomes. Because intellectual property allows a firm to prevent commercial activity, the role of the Wisconsin Alumni Research Foundation (WARF) can provide a key guiding role. The resulting commercialization has the potential to bring Wisconsin additional high paying jobs.

The second option, implementing new crops, has the potential to benefit Wisconsin's agriculture sector. Critical to benefiting farmers, is the vertical integration of producing and processing crops. In the example of the UW phytase experience, we see that harvesting and processing equipment can be cooperatively owned. Depending on the ultimate user of the new crops, there is an opportunity for Wisconsin's farmers to own still further processing opportunities. For example, cellulase producing alfalfa could be used by a lignocellulosic ethanol processor. If that processor was owned in whole or in part by Wisconsin farmers, the farmers are able to capture income from the crop production, harvesting, initial processing, and the manufacturing of ethanol.

The ability for Wisconsin to capitalize on new crops is dependent on the market being receptive to the products. In some cases, such as enzyme production for ligno-cellulosic ethanol production, an established market for the production chain does not exist. However, state policy can help enable the development of the market. Not only might this include the research direction, but also by forming state incentive or purchasing requirements to nurture the market. Entirely new industries could be developed in Wisconsin. These might include a ligno-cellulosic ethanol industry or even an industrial enzyme supply industry. At the most future looking, the potential could go to high value pharmaceuticals or designing crops that meet a specific high value niche need.

Opportunities

- New crops offer Wisconsin farmers potentially high value crops and new income opportunities.
- May offer opportunities to generate income on conservation land without jeopardizing the intent of conserving lands.
- Wisconsin can develop intellectual property to use in-state and/or license out of state.
- New crops may support a larger Wisconsin based chemical industry either through direct conversion of plant material or via providing processing aids, such as enzymes.

Hurdles

- Intellectual property owners can limit the commercialization of new crops.
- Technology and market risk create substantial hurdles for investors.
- Transgenic research creates many possibilities, but commercialization is not always possible. Just because an opportunity exists does not mean it should be pursued.
- Farmer acceptance is not likely unless an established market can be demonstrated.
- Farmer acceptance is not likely unless the new crop can be easily established or disestablished with little additional cost or risk.

Biorefining Opportunity

To illustrate these opportunities, we look at alfalfa and switchgrass to paint the picture of the potential and the challenges new crops and dedicated crops face in supporting the bioeconomy. Other crops should not be dismissed, however; nut crops could offer major new sources of oils, and hybrid poplars could be an excellent source of lignocellulosic raw materials and make good use of CRP land.

Alfalfa was selected for two reasons. First, it is widely grown in Wisconsin. Second, the UW has done extensive research into using alfalfa for producing enzymes, effectively making the alfalfa plant a biorefinery. The potential to meet demand of some Wisconsin industries and to add value to the alfalfa crop is significant. One potential alfalfa product is phytase, an enzyme additive

UW-MADISON PIONEERS PHYTASE, CELLULASE FROM ALFALFA

The University of Wisconsin is continuing extensive research on plant genetics and the application for the potential strains they develop. In the mid-1990s, UW-Madison developed alfalfa as a potential producer of enzymes. Strains of transgenic alfalfa can be created that emphasize the production of one enzyme or another. Two enzymatic products that have been grown and tested are phytase and cellulase. Phytase is a potential additive to animal feed. Cellulase enzymes can be combined to break down cellulose and hemicellulose into smaller sugars. Both of these applications have important roles to play in the biobased economy.

Phytase is a naturally occurring enzyme in plants and fungi. For non-ruminant animals, such as pigs or poultry, phytase can be a useful additive to feed. In the United States, phosphorus is added to pig or poultry feed to ensure sufficient nutritional phosphorus is available for the animals. The excess phosphorus simply moves through the animal's digestive tract and is deposited in manure. The problem of phosphorus build up in soils is a critical issue for some Wisconsin watersheds and is a major driver behind manure nutrient management efforts.

With the addition of the phytase enzyme, the animals can more easily absorb the phosphorus in the grains that they are fed. The phytase significantly reduces the needs for phosphorus additions to animal feed. The impact on phosphorus levels in critical watershed soils is potentially significant and could allow for greater expansion of animals in those watersheds. Further, the use of inexpensively produced phytase from alfalfa can cause feed prices to drop as the large amounts of phosphorus additions are no longer necessary. The inclusion of phytase to animal feed is mandated in many European countries and is considered standard practice.

The research conducted by UW-Madison took the scientific potential for alfalfa-produced phytase all the way to the pre-pilot phase using a multidisciplinary team from six areas of expertise:

- Plant molecular biology
- Plant tissue culture and plant physiology
- Protein recovery and purification
- Plant breeding
- Production agronomy and mechanical engineering
- Agricultural economics and rural sociology

The resulting field trial work developed a plan that covered the process from genetics to harvesting to feeding. A business plan was developed that utilized the cooperative ownership of harvesting and processing equipment and marketing of the phytase by farmers. Additional marketable products, such as pigments, were also identified. The phytase was successfully tested in animal feed. Fecal phosphorus was reduced by 60% in animal excrement. The processed alfalfa, with the phytase removed, was found to be a superior feed for dairy cows.

with significant benefits for pig and poultry feed. Another is the production of cellulase, an enzyme class that can help break down cellulose and hemi-cellulose. The production of cellulase from alfalfa could be a critical opportunity for developing lignocellulosic ethanol.

Alfalfa offers great potential as it is already a part of the existing crop rotation plans for many farms. Indeed, the use of alfalfa to produce enzymes can improve the animal feed quality while not detracting from the volume of animal feed. Harvesting techniques and processing developed at the UW extract the enzymes and actually improve the alfalfa as an animal feed. Mixes of alfalfa strains could provide a harvest that has a specific mix of enzymes, making the cropping and harvesting activity a critical part of an eventual enzyme-based industry. The potential exists for vertical integration of production and processing equipment, allowing a farmer-owned cooperative to capture the added value of enzyme production.

Switchgrass is another major crop option. As a perennial crop, it requires little input. Indeed, it grows wild on CRP land. Switchgrass shows potential for direct combustion and co-firing in existing power plants, along with coal. In a crop situation, switchgrass grows for 10 years before replanting is required. Switchgrass helps prevent soil erosion on marginal lands and improves soil quality. Profitable uses for switchgrass may be a way to address the expiration of CRP land payments.

Switchgrass offers a potential carbon sink to address greenhouse gases. Displacing existing crops could offer a significant carbon-capturing benefit as carbon content in soils rises due to unusually deep roots of switchgrass crops. Switchgrass can provide a buffer strip between crops, animals and waterways. Indeed, the harvest and active management of switchgrass on CRP land could improve the habitat for nesting waterfowl.

While the combination of hardiness and erosion mitigation make native grasses appealing for planting on marginal lands, it is also true that crop yields are directly related to land quality. Studies of crop yields have found unmanaged marginal lands to yield a little more than 2 tons/acre of switchgrass, while more aggressively managed and higher quality land can be expected to yield roughly 7 tons/acre. The economics of switchgrass as an energy crop are naturally tied to the achievable yield. At yields of 7 tons/acre, switchgrass is expected to cost around $23/bale. At this price, combustion of switchgrass is roughly cost competitive with natural gas for energy production. In practice, combustion of switchgrass is done most effectively as co-firing with coal and the price of switchgrass will therefore be compared with the much lower price of coal.

An alternative to switchgrass is the use of mixed prairie grasses. A diverse crop has significant environmental benefits, including general hardiness (reliable and with low inputs), soil conservation and habitat development. According to Cornell University researchers, the pelletizing of grasses (including switchgrass) has potential benefits for use in heating systems. High ash contents must be addressed, but the use of pelletized grasses could be a cost effective heating source.

In the future, the value proposition of co-firing switchgrass with coal will most likely be driven by environmental constraints. Co-firing a mixture of 10% switchgrass with coal has been shown to significantly reduce particulates and NOx emissions by enabling a more complete burn of the coal. In the long term, combustion is unlikely to be the most efficient use of switchgrass harvests and this biomass will be diverted for use in fermentation or gasification. Nonetheless, the pathway to higher refining levels of perennial grasses most likely goes through combustion. Further, the impetus for co-firing of switchgrass (or other biomass) with coal will most likely come from efforts to reduce emissions as opposed to reducing fuel costs.

Channel Resources

Alfalfa

In 2004, Wisconsin Agricultural Statistics reports that 2.5 million acres were harvested for forage alfalfa, while 1.6 million acres were harvested for hay alfalfa. Total forage alfalfa amounted to roughly 3.5 tons per acre, or 8.5 million tons total whereas dry hay alfalfa was harvested at 2.6 tons per acre or roughly 4.2 million tons total. For the production of enzymes, forage alfalfa is the most relevant crop. Alfalfa can be harvested three times per year in Wisconsin.

Seventy-one counties grow alfalfa at some level in Wisconsin, but those counties with the most cows tend to naturally grow the most alfalfa. The potential for co-processing enzymes is significant. According to University of Wisconsin research, roughly 1,800 acres of phytase producing alfalfa would provide enough phytase feed additive to address the needs of all of Wisconsin's pig and poultry growers. In the case of phytase, University of Wisconsin research estimates an additional $1,230 per acre per year potential increase in value for alfalfa.

Switchgrass and Prairie Grasses

The current production of switchgrass and prairie grasses is not well known. The potential is even less well understood. Many supporters of switchgrass and prairie grass use suggest that Conservation Reserve Program (CRP) lands would be appropriate to use for managed grass based crops. The goals of CRP protection and grassland

JERUSALEM ARTICHOKE FIASCO

The dark side of new energy crops was chronicled in the book *Jerusalem Artichoke: The Buying and Selling of the Rural American Dream* by Joseph A. Amato. In the early 1980s, the farm economy was suffering and the US was experiencing its second energy crisis. Biomass and new energy crops were being investigated for solving both problems. One such crop promoted in the Midwest was the Jerusalem Artichoke. Jerusalem Artichokes were promoted and sold as a new and exciting crop that would save farms and solve for the nation's energy problems as a feedstock for ethanol.

Jerusalem Artichokes were sold by a company called American Farm Energy Systems. Wrapped in a marketing technique that included religious and mystical overtones, Jerusalem Artichokes were sold to farmers desperate to believe in their promise. In the end, it turned out that American Farm Energy Systems was a scam. There was no market for the Jerusalem Artichokes which the farmers had purchased seed and invested money. Nor did they provide an energy product or a kick-start to the farm economy. Investors—farmers—lost money and the perpetrators went to jail.

The cautionary tale of the Jerusalem Artichoke holds two lessons. First, new crops, particularly dedicated energy crops, that do not fit within landowners' or industry's existing infrastructure or culture are unlikely to produce near-term profits. Second, the farming community has a long memory. The Jerusalem Artichoke has grown to legendary status, and all new crops are viewed through the lens of the Jerusalem Artichoke. Potential dedicated energy crops like switchgrass or even rapeseed have the barrier of history to overcome.

management are thought to be compatible by advocates of grassland use. Enrollment in the CRP totaled 620,962 acres in Wisconsin as of September, 2005. An additional state and federal effort known as the Conservation Reserve Enhancement Program enrolled an additional 100,000 acres, specifically tied to sensitive habitat and watershed areas.

The total acrage in CRP is roughly 15 percent of the area harvested for alfalfa. However, the potential production of switchgrass is roughly double that of alfalfa (tons of biomass) on a per acre basis. General prairie grass production would vary by the mix of crops. If switchgrass were to be grown on land currently used for alfalfa, corn or soybeans, the potential for biomass production is significant. Thus, the resource of switchgrass is probably best thought of as a *potentially* large resource rather than an actual significant resource available now. From a biomass production perspective, production of switchgrass is roughly equivalent to that of corn stover (corn stalks, cobs, and leaves), but without the intensive inputs of corn. From a handling and material uniformity perspective, switchgrass may be preferable to corn stover as a raw biomass resource. The ability for switchgrass to fit into existing crop rotations is a question for further research.

PEST Analysis

Key PEST issues revolve around finding a place for these crops within the Wisconsin agricultural portfolio. From a market pull perspective, the markets are still immature, and so there has not been significant motivation to introduce these crops. The question remains as to their ease of adoption once the motivation is there.

Political / Legal

- \+ Some new crops could enhance sustainable agriculture and receive support from sustainable agriculture organizations.
- ± Use of CRP land could provide income beyond CRP payments. The use of CRP land for production is a sensitive issue and likely highly dependent on the crop and specifics of management.
- ± If sufficient value can be gained by implementing new crops, the new crops could displace existing crops such as corn and soybeans. Corn and soybean processors and trade organizations may not support such an outcome, though the farming community may as a whole.
- – For crops with intellectual property limitations, licensing could pose a significant challenge.
- – The use of transgenic crops could receive a negative public reaction. However, the use of transgenic soybeans and other non-human food crops has been reasonably well received by the farming community as a whole.
- – Existing crop supports do not support new crops.

Economic

- \+ Some technologies may allow for growing high value, niche crops, on marginal land.
- \+ Value added agriculture grants could be targeted at new crops
- ± New crops may require purchasing new equipment for planting, harvesting, and processing. This can benefit the general farm economy so long as the value of the crops provides sufficient revenues to pay for the new equipment.

– Existing crop supports encourage the growing of a few select commodity crops.

Social

+ New crops could change crop rotation patterns.
+ Some new transgenic crops are not used for direct human consumption and thus, would not require new social attitudes toward transgenic crops.
± Alternative uses for CRP land could impact hunting lands, though proper management may allow for improved habitat.
– Market for crops must be shown before farmers will respond by changing cropping practices.

Technological

+ Crop strains can be developed that emphasize one benefit or another depending on end use.
– Technology for harvesting and processing cannot be developed until crop itself is developed. This can create a potentially long time to market for new crops.
– New and innovative crops must be easily established and disestablished for farmers to be willing to undertake risk.

New and dedicated crops represent an untapped potential resource. They can include both low-tech existing plants (like switchgrass) and high-tech transgenic plants (like some alfalfa strains). In some cases the hurdles to new crops are intellectual property. In other cases there is a lack of an established growing and harvesting practice. In all cases there are the combined risk of technologies and markets. The potential benefits to Wisconsin's farm economy are substantial, but will only be possible if a strong market can develop to support the potential uses for these crops.

Context within Integrated Biorefinery

All crops considered for new or dedicated use in the state fit neatly into existing biorefining ideas, all the way from co-firing with coal to developing the enzymes necessary to conduct lignocellulosic fermentation. Alfalfa can be pre-processed prior to being fed to cattle, as shown in the integrated rural biorefinery diagram (see the Farm Manure Management Channel). Switchgrass could provide the necessary

POPLARS FOR POWER IN MINN.

The Laurentian Energy Authority is a joint effort by the Hibbing and Virginia Public Utilities (two separate municipal districts in Minnesota) to go online with a renewable biomass combined heat and power (CHP) plant. The opportunity was presented by Xcel Energy's mandate to produce 110 MW of biomass based electricity. The existing municipal power plants burn coal..

The plan is to purchase a 20-year contract to sell 35 MW of biomass electricity to Xcel Energy by purchasing NGPP-Minnesota Biomass, LLC and moving the project to the existing local entities. The power produced will replace one coal plant, yielding better environmental results as well. In addition, the new joint venture will launch a dedicated tree farm and work to achieve Minnesota Public Utility Commission approval.

The dedicated tree farm of fast growing poplars is not expected to supply all the fuel needs. Forest residues and wood waste is expected to be drawn from as far as 75 miles away. Along with the benefits of renewable power, this particular project has the added benefits of creating new jobs at the tree farm and with the region's loggers, thereby pumping more money into the local economy. The average fuel usage will approach 300,000 bone dry tons/year.

supplemental volume to justify a gasification plant, and could likewise provide plentiful lignocellulose once the technology for isolating and saccharifying the starches is understood. New oil crops would have a natural fit in the biodiesel industry, and hybrid poplars have already been targeted as fuel for power plants.

Biobased Chemicals

Many chemicals used today are synthesized from fossil fuel resources such as petroleum and natural gas. Many of these chemicals can instead be synthesized from biomass. The use of bioprocessing to create (or to supplant) industrial chemicals and enzymes is called “white biotechnology”; for pharmaceuticals, it is “red biotech.” (“Green biotech” refers to agriculture and is discussed in the New and Dedicated Crops channel.)

White biotechnology presents an interesting opportunity for Wisconsin. While the state is ranked 10th nationally for employment in the plastics industry and 12th in plastics shipments, Wisconsin’s role in the chemical industry is otherwise limited. Many of our industries, from papermaking to farming, are heavily dependent on chemicals which are currently imported. What would it take for the state to increase its self-reliance for the chemicals it needs, or even to become a chemical exporter?

The opportunities here are sufficiently broad that we chose to seek outside expertise to determine which routes to chemical production made the most sense for Wisconsin. We contracted with Seth Snyder, Section Leader for Chemical and Biological Technology at Argonne National Laboratory, and Rathin Datta, CTO of Vertec Biosolvents and Senior Advisor in Chemical Engineering at Argonne, to address the idea of Wisconsin’s entrance into the chemicals industry. The full Snyder/Datta report can be found in Appendix A; the workplan on which the report was based can be found in Appendix B. The conclusions from that report are reproduced below as the Channel Summary.

Channel Summary

“In order to present a report that provides valuable insight to the commercial opportunities, we focused on those feedstocks, products and technologies that currently *or* could have a significant impact, i.e.

- they are already in significant use and/or are growing rapidly,
- they have a potential for large use, or
- the products have wide commercial applicability.

“We reviewed several feedstocks, including corn, oil seeds, other crops, forest products and residues and wastes. We considered fuel, chemical and feed products as well as synergies between these products.

“The primary focus of this report is on larger volume products where Wisconsin has competitive advantages due to synergies in the supply chain or the cost/volumes of the biobased feedstocks. These products compete on a cost basis where raw materials and energy are typically the largest operating costs. This is a short scoping study and an initial assessment. Our primary conclusions and recommendations are:

- Wisconsin is a mixed agriculture state, but unlike its agricultural Midwestern neighbors, it also has a preeminent forest products industry.

- Three feedstocks—corn, forest products (pulp and paper and forest residues) and soybeans—are the only ones appropriate for building a biobased chemicals industry for the next decade.
- During the past few years, biobased liquid fuel products, namely ethanol and biodiesel, have been the base drivers for the growth of the industry. In terms of volume, the liquid fuel market is about tenfold larger than chemical products. Thus building a base for these fuels from conversion of the state's competitive resources is a critical part of the strategy for building a biobased chemicals industry.
- For corn, dry milling technology should be the primary path. The potential synergy between the state's dairy industry's feed needs and the wet DDGs from the dry mills should be actively developed and exploited. This synergy can differentiate Wisconsin from the other Midwestern corn-growing states and make it very competitive.
- The initial growth product should be fuel ethanol (the state already has 200 million gallons/year production), followed by opportunistic addition of other biobased chemicals.
- Organic acids—namely acetic, lactic and its derivatives (PLA and solvents) and polyols (1,3-propanediol)—would be some of the prime targets.
- Biodiesel from soybean oil has a strong growth potential. For Wisconsin, developing a synergy between the state's dairy feed needs and the soybean meal and developing use for byproduct glycerol would be important to make it competitive.
- Gasification is the preferential route for higher lignin content biomass and biomass-derived feedstocks. Wood, residues and black liquor from forest product processing are the primary feedstocks that fit this category.
- Developing syngas fermentation/bioprocessing technologies to make ethanol and organic acids such as acetic acid is the recommended technology path for the long-term outlook. Given Wisconsin's preeminent position in pulp and paper and other forest products, this product and technology path would be very important for its long-term competitiveness in the biobased chemicals industry.
- In order to develop a biobased chemical industry, Wisconsin will need to identify and partner with end users. Advantages to consider in the future include carbon dioxide credits to meet Kyoto Accords for European companies.
- Wisconsin has a strong academic and National Laboratory sectors. Many of the technologies require a skilled workforce. Fostering of R&D and training programs in the relevant technologies will help provide the workforce for the biobased industry. In addition, a strong R&D presence will help Wisconsin develop higher value specialty products."

Biorefining Opportunity

Let us consider three white biotech successes:

- Novozyme's process for scouring cotton with enzymes at 80 percent of the cost of using harsh chemicals
- BASF's process for producing vitamin B12 via fermentation at 60 percent the cost of chemical synthesis
- DuPont's Sorona fiber, which is made from corn sugar-derived 1,3-propanediol and has applications as a textile and beyond[1]

Where do such innovations fit into a biobased economy strategy for Wisconsin?

IP as an industry. If a Wisconsin company had developed an enzyme for cotton scouring, it would be a valuable export to draw money into the state, either as a license or a manufactured product. The jobs at such a company would be the high-paying jobs needed to keep Wisconsin's graduates in the state. Without cotton production in the state, however, the multipliers from such a company would be relatively small. In this scenario, white biotech can be compared to any other high-tech field such as semiconductors—indeed, from an economic development strategy standpoint, they are indistinguishable. Wisconsin is only inherently advantaged toward any high-tech industry to the extent that the industry complements the state's existing R&D and industry activities. With regard to the overlap between white biotech and research activities at UW-Madison and elsewhere, that complement is considerable, but the evaluation of the opportunity is unrelated to any of the factors discussed in this document.

New manufacturing industry. The economic development situation described above for the scouring enzyme could hold true for B12 synthesis, as Wisconsin does not currently have a high-volume pharmaceutical manufacturer. Unlike the cotton processing industry, however, Wisconsin has the capability of entering the commodity pharmaceutical production industry, to the extent that it has the capability of entering any new manufacturing industry. Biotech advances that spur new industry in the state could in fact have very large multipliers. This requires that businesses and entrepreneurs within the state be strategically aligned with researchers and able to claim the first-mover advantage embodied in the new technology. One caveat with regard to biobased specialty chemicals is that although the production of these chemicals will require biological feedstocks like those abundant in Wisconsin, the feedstock resource will be insufficient to motivate such a company to locate here because of the high-margin, low-volume nature of these businesses. As Seth Snyder told us, "When a chemical sells for $100 a pound, it doesn't matter whether the feedstock costs 20 cents or 30 cents."[2]

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[1] All examples from http://www.mckinsey.com/clientservice/chemicals/pdf/BioVision_Booklet_final.pdf

[2] Personal communication with Seth Snyder, Dec. 1, 2005.

Existing industry. Textile as a product from corn creates new markets for Wisconsin's agricultural producers. DuPont's Sorona facility is located in North Carolina, and is not likely to relocate, but this is the kind of innovation that Wisconsin is best prepared to exploit, with significant multipliers based on existing industry. (Indeed, Sorona was co-developed by Genencor, a California-based company whose Beloit, Wis. location is one of its three US manufacturing facilities.)

All three approaches offer benefits for the state. Funding and coordinating R&D in Wisconsin in order to capture those benefits may be the most important action required today to ensure long-term gains. Our R&D priorities for the state are detailed in the Research and Development channel.

An important factor to consider when thinking about white biotech and Wisconsin's existing industries are those industries that are not typically considered biobased and are not represented elsewhere in this document. In particular, Wisconsin's plastic industry could be a fertile place for biobased polymers. The plastics industry is Wisconsin's fourth largest industry, with more than 700 companies in more than 50 counties.

PEST Analysis

Key PEST issues include the immature technology and immature market facing biobased chemicals, as well as their significant economic development potential and the opportunity for Wisconsin to apply its R&D expertise.

Political/Legal

+ Low-VOC substitutes for high-VOC chemicals are especially valuable in non-attainment areas.
± In-state production of biobased chemicals is largely driven by in-state demand for biobased chemicals.
– Chemical facilities can be difficult to site.
– Permitting and safety concerns could complicate the construction of the facilities.

Economic

+ Conversion to commodity and specialty chemicals adds perhaps more value to biomass than anything else.
+ Distributed production of chemicals, such as on-farm ammonia production, offers potential price and supply benefits.
+ Institution of a successful new industry will have significant multiplicative economic benefits.
+ Many possibly products means many different approaches and avenues for entering the market and many customers to potentially serve.
+ Feedstock costs are a significant portion of the cost for commodity chemicals, but are less so for specialty chemicals, which reduces Wisconsin's comparative advantage for those higher value products.
– The market for biobased chemicals is immature. There are significant concerns about their competitiveness in terms of quality, reliability of delivery and price.

– Much of the biobased and existing biobased chemical value chain is controlled by large, multinational companies.

Social

+ Biobased chemical production facilities do not have to be refinery-scale to be successful.
+ The development of this industry could play a factor in the retention of UW graduates who might otherwise leave the state to work in this field.
+ Biobased chemicals tend to have reduced environmental impacts through their entire life cycle.

± Biobased chemicals' "green" nature may convey a niche value, but also may face prejudice from change-averse industry.

Technological

+ Wisconsin's R&D strengths will provide many opportunities for technological leadership if pressed to pursue this arena.
+ Transgenic crops that express desirable enzymes can be grown and processed in-state.

± As new methods of biosynthesizing chemicals are developed, they are typically immediately imprisoned by proprietary IP, with one facility selected to produce the chemical for the first few years. This can benefit Wisconsin if a Wisconsin site is selected for production.

– Feedstock quality is necessarily variable, which can impact reliable production of uniform chemicals.

– Much R&D needs to be done in the fermentation arena, including cracking lignocellulosic fermentation.

– Much R&D needs to be done in the thermochemical platform to extract desirable chemicals out of bio-oil and syngas.

Biobased chemicals are an extremely promising arena for Wisconsin. While our biomass resource is significant in determining the industry's viability in Wisconsin, it is the state's intellectual capacity that presents the most promise, as scientists from universities, private industry and federal labs are already at work to overcome the technical hurdles. Wisconsin's relationships with players at all levels of the chemical industry will be important in helping the state learn the directions in which R&D needs to be directed and to determine the needs of those who would purchase the chemicals.

The remainder of this channel description is excerpted from the Snyder/Datta report. The report can be found in its entirety in Appendix X.

Opportunities with Wisconsin's feedstocks

We believe that three feedstocks meet the criteria for Wisconsin to develop a biobased products industry over the next decade. These feedstocks have sufficient production volume, density, and infrastructure to provide economical raw materials.

- Corn grain
- Soybean
- BLG and forest product residues

The corn and soybeans are large opportunities in the southern region and forest products are an even larger opportunity in central and northern Wisconsin.

Biobased chemical products that have significant growth potential over the next 10 years

During the past few years, biobased liquid fuel products—namely ethanol and biodiesel (fatty acid methyl esters)—have been the base drivers for the growth of the industry. In terms of volume, the liquid fuel business is about tenfold larger than that of chemical products. Thus building a base for these fuels from conversion of the state's competitive resources is a very important part of the strategy for building a biobased chemicals industry. Once this base begins to be built, the chemicals that have significant growth potential can be added on to the existing production plants, or plants can be converted to the production of these chemicals. We have highlighted below those that we believe have very significant growth potential over the next 10 years and have a bioprocessing technology path for their manufacture.

Ethanol

Use of ethanol as a motor fuel as-is or as an additive to gasoline is well known and has been practiced for over 100 years in many parts of the world. The amounts produced and used have changed over time and as petroleum derived liquid fuels became dominant after the Second World War, ethanol usage declined. Recently, ethanol is making a comeback and currently it is the primary biomass-derived liquid fuel, mainly derived from two agricultural feedstocks: corn and sugarcane. Ethanol accounts for close to 3% of world gasoline use. The US and Brazil are the primary producers.

In 2004, ~3.5 billion gallons of ethanol was produced in the US, almost entirely from corn. Since the mid-1980s ethanol production has steadily grown with the support from the federal excise tax credit of 52¢/gallon of ethanol. In recent years the rate of growth in the US has accelerated due to:

- decline and phase out of methyl tertiary butyl ether (MTBE) as a gasoline oxygenate because of its environmental problems
- state-wide ethanol mandates
- increased cost of petroleum
- tax support incentives that are expected to be continued over a long period.

The 2005 Energy Bill further mandates an increase to 7.5 billion gallons/year. Farmer cooperatives account for most of this increase in production. In the past few months, the price of ethanol has decoupled from gasoline and is actually selling below gasoline prices, even without the tax credit.

In Table 1, we summarize current and potential ethanol utilization in Wisconsin. If Wisconsin adopts a 10% ethanol fuel mandate, this will be a strong driver for growth of the industry to meet internal demands. Just from corn production, Wisconsin can meet a 10% ethanol mandate and still grow significantly as an ethanol exporter. In Table 2, we estimate percent utilization of corn to produce targeted ethanol levels. Considering current corn conversion to ethanol, direct corn exports, and partnering with the animal feed industry, 50 percent utilization is conceivable. At 500 million gallons/year production, Wisconsin would be a substantial ethanol exporter, but not large enough to overwhelm the 7.5 billion gallon/year market in 2012.

Table 1: Ethanol-blended fuel use in Wisconsin[3]

Fuel (million gallons/year)	
2520	Motor gasoline use
1079	Ethanol blended fuel use
108	If blend averages 10 %ethanol
252	Ethanol use with proposed10 % ethanol mandate
144	Additional ethanol usage with 10 % mandate
210	Current ethanol production capacity

Table 2: Potential annual ethanol production from corn[4]

% of Corn Crop	Corn (millions BU)	Ethanol (millions gallons)
100	350	963
50	175	481
25	88	241
15	53	144

Biodiesel

The growth of biodiesel in the US is more recent, and serious promotion for its production and usage began around the year 2000. In the year 2004 about 30 million gallons were produced, growing rapidly from 2 million gallons in the year 2000. Currently, there are about 30 biodiesel production facilities (many of them small) scattered in many states. Some of the larger ones are located in Iowa, Texas and California (NBB, 2005). Recently Cargill announced that they will build a 37.5 million

[3] Fuel use in Wisconsin reported by the Federal Highway Administration (EIA, 2005), proposed E10 ethanol mandate reported by the Wisconsin State Journal (2005), ethanol production capacity reported by Ethanol RFA (2005).

[4] Corn production from ECW (2005), ethanol production assumes 2.75 gallons/BU.

gallon facility in Iowa with production commencing in 2006 (Cargill, 2005). The 2005 Energy Bill includes subsidies for biodiesel production of $1 per gallon. Biodiesel is expected to grow rapidly, with rates as high as 100% for the next few years. In Table x we summarize distillate fuel use and the potential for soybeans to produce biodiesel for the Wisconsin market.

Soybean oil is the primary crop in the US that provides protein feed and oil. A small fraction of this oil is now going to the biodiesel production. B2, a 2% blend, is used to increase lubricity. A standard B20 (20%) blend does not require vehicle modification and has become very popular (Tyson, 2001).

Organic acids

Acetic acid is a 16 billion pound product that is almost entirely produced from natural gas via a catalytic route. Acetic acid could be produced by carbohydrate or syngas fermentation (Gaddy 2004, Snyder 2005b, Heiskanen, 2004).

Lactic acid and derivatives have received significant press recently. This is primarily driven by two derivative products: the PLA biopolymers and biosolvents or solvent blends (acetates, lactates, or Vertec Biosolvent's solvent blends, 2005).

In comparison to ethanol, acetic and lactic acid have a distinct advantage. To maintain electron balances, theoretical yield for ethanol production from sugar (or syngas) is about 50% based on feedstock mass. Theoretical yields for acetic acid and lactic acid are about 100% based on feedstock mass. Therefore, these acids provide a potential higher product yield.

Other organic acids such as succinic or 3-hydroxy propionic have been identified as potential large volume platform chemicals (Werpy, 2004), but neither the markets nor technology are available at this time.

Polyols and other chemicals

DuPont is actively developing technology to produce 1,3-propanediol (PDO) for production of fibers based on 3GT. There are several potential applications for sorbitol (Werpy, 2004). Glycerin, the co-product of biodiesel, is a large-volume material used in the personal care products industry, and could be a feedstock for several new products and uses.

In 2004, the DOE Office of Biomass Programs conducted an analysis of the Top Platform Chemicals that could be produced from biomass to replace platform petrochemicals (see Table 4, Werpy, 2004). Most of these products are organic acids or polyols. The report identifies the good potential candidates for R&D investments that could provide the next generation of biobased chemicals used in an integrated biorefinery. ECW (2005) has completed a comprehensive study of biobased fuel and chemical products and we do not have to repeat them here.

In comparison to fossil-based products, biobased products require more distinct, and potentially more costly, product separations and recovery strategies. These differences are based on recovery of biobased products from dilute aqueous solutions, and the need to manage pH while producing acids as products or co-products (Hestekin, 2002).

Table 3: Top 12 candidate platform chemicals from biomass

Four carbon 1,4-diacids (succinic, fumaric, and malic)
2,5 Furan dicarboxylic acid (FDCA)
3-Hydroxy propionic acid (3-HPA)
Aspartic acid
Glucaric acid
Glutamic acid
Itaconic acid
3-Hydroxybutyrolactone
Glycerol (glycerin)
Sorbitol (alcohol sugar of glucose)
Xylitol/arabinitol (sugar alcohols from xylose and arabinose)

Source: Werpy (2004)

Synergies

One of the strategic issues and questions that often arise when discussing biobased chemicals vs. already entrenched petrochemical is the relative production plant size. This is a complex issue and detailed discussion and specific economic factors are beyond the scope of the report. However, some important general factors come into play. For biobased chemicals, feedstocks cost is often 50 to 70% of the products cost. If that is competitive with petrochemical feedstock, then the production plant size does not have to be very large. Thus for example: The ethanol from dry mill is competitive with the wet mill at a much smaller production volumes (at 25-50 million gallons/year compared to 100-200 million gallons/year). Moreover, ethanol is now competitive with gasoline at current crude oil prices without subsidies despite the fact the petroleum refineries are two orders of magnitude larger than ethanol plants.

In the next section we have highlighted some of the technologies and integrations that will be critical to consider and develop for making Wisconsin become competitive in future of the biobased products industry.

Technologies

There are three distinct technological paths to convert biobased feedstocks to fungible products.

- Conversion to fermentable sugars followed by fermentation
- Gasification to syngas and either use of the syngas as a fuel or conversion by catalysis or fermentation
- Transesterification of fats and oil to biodiesel (alkyl esters) and recovery of the glycerin co-product.

Fermentable sugars/Fermentation

Wet milling and dry grind milling are the two major processes used to produce bioethanol from corn. Wisconsin has several dry grind mills in operation or planning (Table 5). The capital costs and infrastructure needs for dry milling are much lower than wet mills.

Table 4: Ethanol plants in Wisconsin

Ethanol Plant	Location	Capacity (million gallons/year)	Comment
ACE Ethanol	Stanley	39	
Badger State Ethanol LLC	Monroe	48	
Central Wisconsin Alcohol	Plover	4	
United WI Grain Producers	Friesland	49	
Utica Energy LLC	Oshkosh	48	
Western Wisconsin Renewable	Boyceville	40	under construction

Source Ethanol RFA (2005)

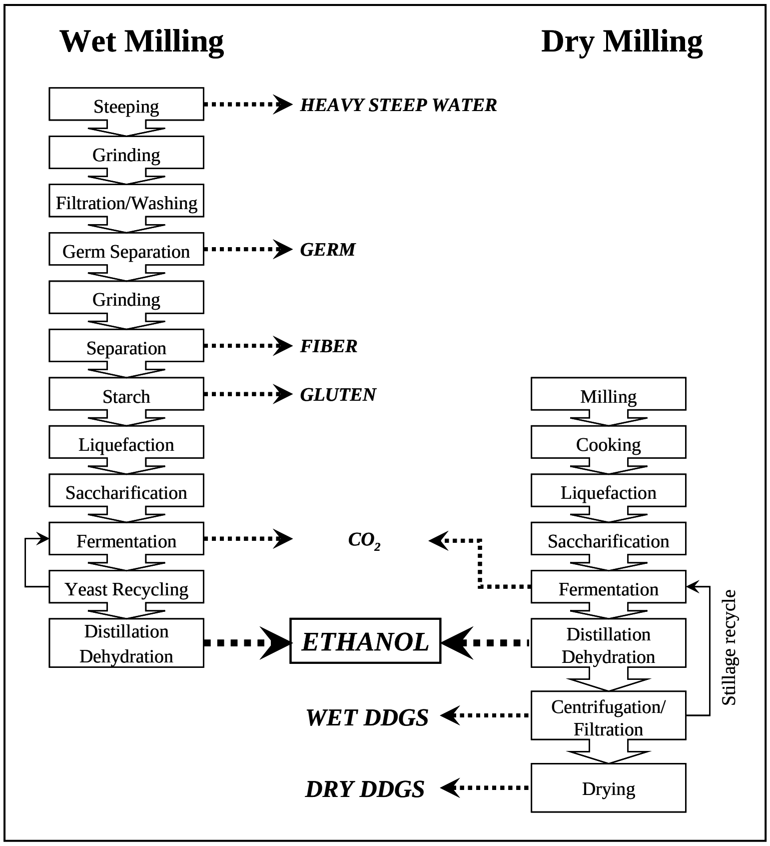
In dry mills, dextrose is readily fermented by yeasts to ethanol. The theoretical yield for dextrose (sugar) to ethanol is 51% (Eq. 1) and typically 95 % of this theoretical yield is achieved in a well run and optimized plant.

$$C_6H_{12}O_6 \rightarrow 2\ C_2H_5OH + 2\ CO_2 \qquad (1)$$

Production of CO_2 is required to maintain the electron balance of the reaction.

Dry milling technology is simpler than wet milling and amenable to smaller scale plants (Figure 2). Corn is ground, slurried and hydrolyzed (at temperature of 90 to 100 °C) with thermostable alpha-amylase enzyme. This mash is then cooled and fed to fermentors with the addition of glucoamylase enzymes and yeast. The fermentations are run in non-sterile conditions at low pH of around 3 to control bacterial contamination and are usually run as batch fermentation with some yeast recycle. Typical ethanol concentrations of 8 to 10% (v/v) with 95% of the theoretical yields (~2.75 U.S. gallons per bushel) readily achieved and typical fermentation time range between 30 to 40 hrs. This fermented “beer” is directly distilled and azeotropic ethanol is produced overhead, which is further converted to anhydrous ethanol by molecular sieve or pervaporation technology. The bottoms now contain all the unfermentables: corn fiber, germ, oil, protein and the yeast. This is usually centrifuged. The liquid fraction (stillage) is recycled to the fermentor and the solids fraction is usually further mechanically pressed to recover more water to make wet distillers grains and solubles (wet DDGS) or dried further to make dry DDGS. The handling, infrastructure and sale of the DDGS have been some of the important issues for the viability and economics of the dry milling technology. Wet DDGS cannot be stored and need to be consumed as animal feed within a short time. Thus, many of the smaller dry mill plants need and have local farmers and farm cooperatives that are financially committed to the ethanol plant, corn supply and the purchase and use of the wet DDGS. More recently, the larger farm cooperatives and agricultural enterprises have invested in standardizing and promoting DDGS use. Recently the dry milling ethanol enterprises are being consolidated and larger plants that produce dry DDGS are emerging. However, the solids handling drying for the DDGS are often the largest component of the equipment capital and energy consumption and the "DDGS issues" will continue to be very important to the dry mill technology. Typical dry mills produce about 25 – 50 million gallons of ethanol per year and capital costs are in the range of $1 per gallon of capacity.

Figure 1: Comparison of corn wet and dry mill processes



Synergies between dry mills and distiller grains

Wisconsin has enormous advantages in the supply chain because of the close proximity of the high-density corn industry and the dairy industry. The centers of these industries are only about 100 miles apart. This enables partnering and developing a supply chain for wet DDGS. By avoiding the costs and energy required for drying the wet DDGS to produce dry DDGS, Wisconsin dry mills will have a competitive advantage over other Midwestern corn producing states. Concerns regarding use of wet distiller grains have been addressed:

> *The main considerations between the use of wet versus dried CDG are handling and costs. Dried products can be stored for extended periods of time, can be shipped greater distances more economically and conveniently than wet CDG, and can be easily blended with other dietary*

ingredients. However, feeding wet CDG avoids the costs of drying the product (Schingoethe, 2001)

In terms of volume, ethanol as a liquid fuel business is about tenfold larger than potential of the chemical products. Thus building a base from corn conversion and developing the synergy with the dairy feed is a very important part of the strategy for building a biobased chemicals industry. Once this base begins to be built, the chemicals that have significant growth potential can be added on to the existing production plants or plants can be converted to the production of these chemicals.

Examples of additional chemicals that could be produced from the fermentable carbohydrate include all of the potential bioproducts that were discussed earlier. These are: organic acids and their derivatives (acetic, lactic, succinic, 3-hydroxy propionic); polyols such as 1,3-propanediol and other platform chemicals. For each of these chemicals, the fermentation strains and recovery processes would be different and those are being developed by the current manufacturers of the products. However, note that fermentable feedstock cost would be >50% of the cost of production of these chemicals and the competitive feedstock cost position is an important factor is decision-making for locating manufacturing plants.

Gasification and conversion of syngas to fuels and products

Gasification is the preferential route with higher lignin content biomass and biomass-derived feedstocks. Wood, residues and black liquor from forest product processing are the primary feedstocks that fit this category.

Gasification and pulp & paper mills

Wood gasification has been developed and widely practiced over the past century. particularly before WWII, in Canada, US and Europe. The scale of operations have ranged from small portable gasifiers to run engines to mid-sized gasifiers to run heat and power for wood processing plants, paper mills etc. (Goldman, 1939). Thermal efficiencies of 70-80% have been readily achieved when dried wood or densified biomass with 20% moisture were used. More recent work with biomass gasification with bagasse has been reported (Macedo, 2004). Generally, gasification of wood or densified biomass with low to moderate moisture content (20 to 30%) gives good thermal efficiency to readily produce a mixed gas composed of CO, H_2, CO_2, H_2O vapor with small amounts of CH_4 and tar and some ammonia and sulfides (100 to 1000 PPM).

In chemical pulping, the cellulose is separated from the hemicellulose and lignin. The cellulose is used to produce paper and other products. The separated hemicellulose and lignin is recovered as a solution called spent or black liquor that also contains the spent chemicals (sodium carbonate and sodium sulfide or sulfite) (Wag, 1997). It is essential that the energy content and chemicals of the spent liquor be recovered. The Tomlinson technology is over 80 years old and a significant fraction of the recovery boilers in the US are reaching the end of their service life. There is intense interest in having improved black liquor processing technology commercially available in the 5 – 10 year timeframe (Larson 2003). The pulp & paper industry has identified significant benefits to replacing recovery boilers with gasification systems. These include significantly increased power production efficiencies, ability to increase yields with advanced pulping chemistries made possible by gasification, flexibility to process biomass and other mill waste streams, and the flexibility to produce other biobased chemicals and fuels. There are two leading BL gasification processes: ThermoChem Recovery International uses a low temperature, indirectly-heated fluidized bed steam reforming technology to gasify organic feedstocks (TRI, 2005a); Chemrec (Sweden), the other major BLG provider, uses a high temperature partial oxidation processes that uses an air-blown, circulating fluidized bed gasifier (Berglin, 2003, Chemrec, 2005). TRI is completing a commercial demonstration with Georgia Pacific at Big Island, VA, and Chemrec is completing a commercial demonstration with Weyerhaeuser at New Bern, NC (Chemrec 2002, TRI, 2005b, Larson, 2003).

The black liquor solids (BLS) contain about half of the energy of the wood feedstock (Larson 2003). The BLS is burned in the boilers to recover the sulfur and sodium pulping chemicals for recycle, and provides all of the process steam and some of the power for the P&P mill (Larson 2003).

The TRI process produces a syngas with a mixed composition of H_2, CO, CO_2, H_2O, NH_3, H_2S, etc. In the steam reformer system, the H_2S in the product syngas is recovered by amine scrubbing prior to use as a fuel gas. Current sulfur recovery technologies add significantly to the total capital and operating costs of the system. Reducing capital and operating costs will significantly increase conversion to gasification in pulp & paper mills. One advantage of starting with black liquor is that the feedstock is already available at the pulp & paper mill. Avoiding the need to develop the infrastructure for biomass collection increases the likelihood of commercialization.

The state energy authority has conducted an impressive analysis of the advances in the BLG and wood gasification technologies (ECW, 2005).

Taking a typical mill size of 3000 MT of black liquor solids (BLS) and a reasonable conversion of 100 gallons ethanol/dry ton BLS, a pulp & paper mill could produce about 100 million gallons of ethanol per year. The pulp & paper ethanol production falls between the size of a dry and a wet corn mill. Therefore, the fuel output of the pulp & paper mill will be well matched with the existing industry. Conversion of a 100 Kraft mills to ethanol producers would yield 10 billion gallons of ethanol/year, more than twice the size of the current U.S. bioethanol production. Organic acids such as acetic and other alcohols such as butanol could also be made from syngas.

Given Wisconsin's preeminent position in pulp & paper and other forest products, this product and technology path would be very important for its long term competitiveness in the biobased chemicals industry.

Fuels and chemicals from syngas

Syngas, a mixture of CO, H_2/CO_2 and other smaller components, can be derived from any carbonaceous feedstock—coal, natural gas, petroleum residues and biomass by a wide range of gasification technologies. Extensive R&D, as well as commercialization, of syngas from coal, natural gas and petroleum residues to liquid fuels have occurred over the past 80 years. The three products that are relevant from the biobased chemicals view point are:

- Fischer Tropsch liquids
- mixed higher alcohols via catalytic technology
- ethanol and organic acids by fermentation and bioprocessing

Due to the diffuse nature of growth and collection, biomass feedstocks cannot be procured and processed in very large sized plants (typical size is 1000 - 3000 MT/day). Due to the heterogeneous nature, the feedstocks will contain proteins and sulfur and the raw syngas will contain sulfides, ammonia and other impurities. Therefore, important factors for technical and economic relevance and competitiveness are:

- gas purity and conditions needed for the conversion
- optimum size for commercial plants.

A recent report has conducted a comprehensive screening analysis of syngas conversion technologies with special emphasis on the potential for biomass-derived syngas (Spath, 2003).

Chemical/catalytic technologies

Fischer Tropsch liquids
Liquid fuels from coal-derived syngas by Fischer Tropsch (FT) process was developed and used by Germany in WWII and recently South Africa, which produced 13 billion pounds in 2002. These liquid fuels are long-chain hydrocarbons that could be used as diesel or heavy-duty engine fuel. Biomass-derived syngas was never considered or utilized for these large-scale plants.

The general process flow diagram is presented elsewhere (Spath, 2003). There are four main steps: syngas generation, gas purification, FT synthesis and product upgrading. The syngas generation conditions depend on the feedstock; usually it is high temperature gasification in presence of oxygen and steam. The gas cleanup requires the steps of particulate removal, wet scrubbing, catalytic tar conversion, sulfur removal via amine scrubbing, etc. The impurity tolerance of FT synthesis gas is very strict: sulfur – (60 ppb to 200 ppb), nitrogen - (10 ppm NH_3, 200 ppb NO_x, and 10 ppb HCN), halides - (10 ppb) (Boerrigter, 2002, Dry, 2002).

Depending on the type or quantities of products desired, either low (200-240 °C, 7-12 bar pressure) or high temperature (300-350 °C, 10 to 40 bar pressure) synthesis is used with either iron-based or cobalt-based catalysts. The reactions are very exothermic and a variety of reactor types and geometries has been used. The low-temperature synthesis produces linear hydrocarbons and waxes which can be further cracked and processed to make diesel-type liquid fuels. The high-temperature synthesis produces more of the unsaturated olefinic products, which can be further processed by oligomerization, isomerization and hydrogenation to gasoline type liquid fuels.

From a biomass conversion viewpoint, the FT technology and products have very significant impediments. Oxygen or oxygen-enriched air is required. The raw gas has to be cleaned to stringent standards and pressurized. The reactions are exothermic and intermediates are produced that have to be further converted to the desired fuels. A wide variety of byproducts are produced and they have to be sold as specialty products to make the operation profitable. For example, the SASOL plant sells about 200 specialty co-products while providing the primary liquid fuels from its large operations. And most significantly, due to the complexity of the operations, the FT technology works at very large scale (10 – 20 million pounds/day or higher) which is conducive to fossil-derived feedstocks, not biomass (Bain, 2005; Spath 2003)

Mixed alcohols

Methanol is produced worldwide from syngas by well developed catalytic processes, and currently ~90 billion pounds are produced worldwide, primarily from natural gas. In the past, i.e. late 19th and early 20th century, methanol was produced from biomass by wood distillation and later by syngas from wood gasifiers. These are not likely to come back and become competitive. Furthermore, because of its phase behavior and other properties, methanol is not compatible as a supplement to gasoline or diesel fuel. Thus the large usage of methanol as a liquid fuel would require a separate infrastructure for internal combustion engines and fuel supply and this not likely to happen soon.

Other alcohols such as ethanol or a mix of higher alcohols can potentially be derived from syngas, either by biocatalytic process or by catalytic process technology. Mixed alcohols are more attractive and amenable to gasoline-blending stock than methanol, because of higher vapor pressures, phase behavior and octane numbers. There are several avenues for the development of the technology and two—modified methanol synthesis or modified Fischer-Tropsch technologies—are being pursued. Depending on the process conditions and catalysts used, the most abundant products are methanol, CO and CO_2, which then undergo higher alcohol synthesis by CO insertion to form C-C bonds and further homologation and hydrogenation. The product mixture contains primarily ethanol followed by smaller fractions of propanol, butanol, etc. The yield and selectivities are low. The typical process conditions range between 250 to 350 °C, 50 to 250 bar pressure (Spath, 2003). The reactions are exothermic and reactor geometries similar to the FT technology are needed. The gas conditioning and clean up requirements are similar to that of methanol and Fischer-Tropsch technologies, except for one of the catalysts developed by Dow Chemical Co. in the 1980s, which uses molybdenum sulfide and is therefore sulfur tolerant, but its nitrogen tolerance is unknown (Herman, 2000).

Unlike FT technology, there are no commercial plants to produce mixed higher alcohols for liquid fuels and the products have not been approved for gasoline blending (Lucero, 2004, Spath 2003). From a biomass conversion viewpoint this technology has technical and size incompatibility impediments similar to that of the FT technology (Bain, 2005).

Fermentation/bioprocessing technologies

In Figure 3, a schematic process for fermentation of BLG syngas to ethanol is presented. Several organisms are known to produce ethanol from syngas including *Clostridium ljungdahlii* (Gaddy 1992). Other organisms such as *Acetobacterium woodii* and *Clostridium thermoaceticum* are known to produce acetate from syngas. There are particular advantages to BLG syngas fermentations and potential technical barriers summarized elsewhere (Snyder, 2005a). The two most notable advantages are:

- the volume of feedstock available to P&P mills is much more suitable to fermentation than chemical conversion
- microbial strains could be adapted to crude syngas much more readily than chemical catalysts.

In Table 7 we estimate production of ethanol in Wisconsin's existing pulp & paper mills by BLG fermentation.

This estimate of 168 million gallons/year of ethanol only includes BLG feedstocks that are already collected and available for conversion. Looking forward, the larger forest product residues and pulp & paper mill residues as an available feedstock of about 3-4 million tons/year could be used to produce an additional 300-400 million gallons/year of ethanol. Please note that this level of production is from residues that do not displace the existing fungible forest products. Direct production of forest products for fuels and chemicals production could be substantially larger.

The significant opportunities and challenges of producing fuels and products from syngas are:

- Significant quantities of biomass derived syngas could become available from the implementation of BLG in Wisconsin, which is beginning in the pulp & paper industries.
- Fischer-Tropsch or mixed alcohol and derivatives technologies that are being developed are more suitable for syngas derived from fossil sources such as coal or remote natural gas than biomass feedstocks. This is because the amounts of biomass syngas do not meet the economies of scale of these chemical processes.
- Ethanol and acetic acid by anaerobic bioconversion of crude syngas is an emerging technology that has a very significant potential to be compatible with biomass feedstocks and also produce ethanol at prices less than $0.75 per gallon.
- Further development of this technology would require organism/strain development, bioreactor design and development and integration with advanced separations technologies.

Figure 2: A schematic process for fermentation of BLG syngas to ethanol

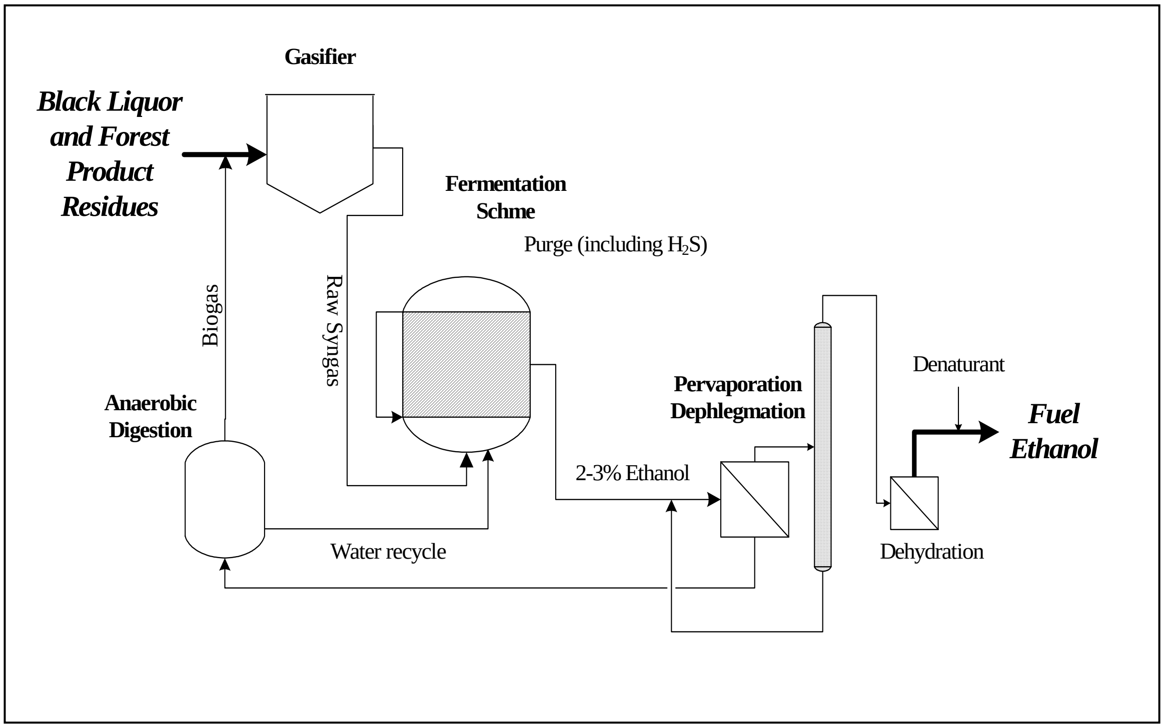


Table 5: Black Liquor Gasification to ethanol potential

Table 6: Production of ethanol in Wisconsin's existing pulp & paper mills by BLG fermentation

Kraft Mill Name	City	Pulping Capacity (tons/year)	Ethanol (million gallons/year)
Thilmany (formerly IP)	Kaukauna	203,000	32.1
Stora Enso N.A. -Pulp Mill	Wisconsin Rapids	658,000	103.9
Domtar Industries (GP)	Nekoosa	108,000	17.1
Wausau-Mosinee	Mosinee	96,000	15.2
Totals		**1,065,000**	**168.2**

BLG notes: Only mills with Kraft (sulfate) chemical pulping are candidates for BLG. Chemical pulping capacity (which may be less than paper making capacity) is used for this table. Sources: Kraft mills data from ECW (2005), BLG available per ton of pulping capacity available from Larson 2003, conversion of BLG to ethanol from: Snyder (2005a).

Transesterification

Biodiesel is the methyl ester of fatty acids derived by transesterification of fat or vegetable oil, which are fatty acid triglycerides. The biodiesel production process has been described elsewhere. The reaction is simple transesterification with base or acid catalyst. The methanol is in excess in the reactor, the reacted phases separate and the methyl ester/methanol phase is washed, purified and the excess methanol is evaporated and recycled. Currently 95% of the theoretical yield is achieved with this process. The oil feedstock is the largest cost factor in the production process. For example, in the soybean oil accounts for close to 90% of the production costs. (Hamilton, 2004)

The glycerin phase is neutralized, the residual methanol is evaporated and recycled and the crude glycerin, with some of the residual fatty acid, is the main byproduct. This has to be further purified to produce a fungible co-product of industrial-grade glycerin, or the crude product has to have a useful outlet. As the production and usage of biodiesel increases, the glycerin issue will become increasingly important. Purified glycerin is sells for 50-75¢ per pound in the consumer products markets. If biodiesel grows rapidly and the glycerin is purified, this price could decline sharply, and there could be serious market disruptions.

For example, if the biodiesel production increases as envisaged, to 3 billion gallons, about 2 billion pounds of crude glycerin will be produced. This will approach or exceed the refined glycerin production of the oleochemical industries for consumer products. Thus just making refined glycerin from the crude is not going to be a viable option. Current glycerin producers are investigating replacement of other glycols such as ethylene and propylene glycols in their existing applications, which may be difficult to penetrate. Additional opportunities where there is a potential for growth could be based on bioconversion technologies. These are representative large volume opportunities:

- Fermentation to ethanol for biofuels
- Bioconversion to 1,3-propanediol for emerging DuPont's 3GT polymers
- Carbon source for fermentation feedstock to supplement dextrose syrups

Research and Development

Channel description

Biobased industry presents Wisconsin with a unique opportunity to build off its biomass portfolio to gain economic advantages. In this economic development picture, environmental stewardship and industrial best practices are aligned with significant business opportunities. This is too valuable an opportunity for Wisconsin to occupy the passenger's seat. Being the driver begins with a commitment to in-state research and development, allowing Wisconsin to take the best advantage of existing technologies while positioning itself to reap the benefits of the best new ideas from public and private research. This R&D push will come from the state's universities (principally the UW System), private high-tech industry, and federal research facilities.

Channel summary

Wisconsin's universities and high-tech industry understand the potential of an emerging bioeconomy well enough to be strongly positioned to take advantage of it. However, a lack of R&D funding and coordination may prevent the state's effort from gaining momentum and realizing its full potential. Not only could organized R&D yield near term results, but it is the key component of the infrastructure the state needs to support long-term and very long-term bioindustry efforts. Developing intellectual property is a critical part of the bioeconomy value chain.

Hurdles

- Bioeconomy development has not been a funding priority in Wisconsin.
- Research efforts in the state are not aligned; the current set-up of a number of "silo" efforts is not conducive to advancing the bioeconomy. There is a leadership vacuum with regard to someone that can give the state researchers cues as to the state's priority research areas.
- Intellectual property issues can stall any particular effort before it has left the ground.
- State and university goals are not aligned to support emerging bioindustry efforts and keep these efforts in Wisconsin.

Opportunities

- Wisconsin has an ideal combination of university, industry and federal research staff and facilities for R&D work.
- Increased activity in this arena will provide high-quality jobs for the state's college graduates – the kind of jobs they currently leave Wisconsin to find.
- University researchers may have many biorefining technologies worthy of commercialization that are going unnoticed in their labs today.

Biorefining opportunity

Nothing is more likely to bring Wisconsin significant future gains in biorefining than a robust set of targeted/coordinated in-state research and development. While the speculative nature of research makes it impossible to predict or quantify the specific benefits that could accrue, it is clear that the bioeconomy poses significant research needs, and that there will be increasing competition for funds to undertake that research as the potential of biorefining is more widely recognized.

The analysis in the other channels has brought into relief the needs for applied research associated with executing the technologies they require. Those needs include:

- Densification and export of wood residues
- Conversion of syngas to liquid fuel (e.g. Fischer-Tropsch or fermentation)
- Value prior to pulping (i.e. hemicellulose extraction, enzymes, fermentation)
- Methods to increase or improve biomass supplies
- Environmental profiles of biorefining technologies
- Non-electricity use options for biogas
- Smaller and modular anaerobic digestion systems
- Lignocellulosic ethanol processing methods for Wisconsin crop residues
- Pyrolysis oil characteristics and market opportunities
- Pyrolysis char as soil amendment
- Crop residue harvest, storage methods and economics
- Fiber composite uses for Wisconsin feedstocks
- Public, private and hybrid business models and their associated technical, legan and business issues

The bioeconomy's research needs are more expansive even than this, however. Only through innovative basic research will the state discover new biorefining technologies that might add even more value to biomass than do existing technologies and processes.

Channel resources
Wisconsin has three major components to its biorefining R&D capacity: the University of Wisconsin System and other universities; private industry; and federal research facilities.

University of Wisconsin System and Other Universities
The University of Wisconsin System consists of 13 four-year campuses and 13 two-year campuses, as well as an established Extension system that has a presence in all 72 Wisconsin counties. Within the UW System, a number of entities are playing a direct role in advancing the bioeconomy:

- **University of Wisconsin at Madison**. In September 2005, Washington Monthly magazine ranked UW-Madison as the No. 1 research university in the country based on the university's contribution to society. The UW-Madison campus ranks third in the country for research expenditures and is unique in that it houses all five life science colleges on a single campus. Over 15% of the research funding at UW-Madison goes to agriculture and the life sciences. Among the campus's R&D attributes:
    - **Biotechnology Center**. Now entering its third decade, the Biotech Center serves to coordinate related research "silos" at the university, as well as reach out to industry. The Center's state-of-the-art facilities include the

Gene Expression Center, DNA Sequencing and DNA and Peptide Synthesis—attributes that make the Biotech Center a hotbed of cutting-edge research. The Center also houses the Genome Center of Wisconsin, reflecting the strides Wisconsin has made in genomics. While the Biotech Center does not have its own faculty, it is recognized as a critical asset for UW researchers in these fields. Much of the work performed at the Biotechnology Center is not of interest to this report, such as work on the human genome, but other work is directly on point, such as plant genetics and industrial biotech.

- **College of Agriculture and Life Sciences (CALS)**. CALS is the state's only land-grant agricultural college, and is home to the Biological Systems Engineering program. CALS oversees 13 Agricultural Research Stations throughout the state, including greenhouses and shared facilities with the USDA Dairy Forage Research Center (see below). The CALS Research Division organized its research from 2000-2004 around the following goals, with the percentage in parentheses after each goal indicating what portion of the approximately $300 million research budget it was allocated:
    - Through research and education, empower the agricultural system with knowledge that will improve competitiveness in domestic production, processing, and marketing. (36%)
        - Major crop and animal production systems
        - Low-input production systems and non-traditional enterprises
        - Biological mechanisms of development and function
    - To ensure an adequate food and fiber supply and food safety through improved science based detection, surveillance, prevention, and education. (24%)
        - Disease resistance mechanisms
        - Pest and pathogen management
    - Through research and education on nutrition and development of more nutritious foods, enable people to make health promoting choices. (9%)
        - Enhancement of food quality and safety
        - Outcome and rationale for food choices
    - Enhance the quality of the environment through better understanding of and building on agriculture's and forestry's complex links with soil, water, air and biotic resources. (18%)
        - Conservation and management of natural resources
        - Interactions of agriculture and forestry with natural ecosystems
    - Empower people and communities, through research-based information and education, to address the economic and social challenges facing our youth, families, and communities. (13%)
        - Agricultural and natural resource economics
        - Human dimensions of agriculture and natural resources

        - Science literacy and information access

These goals, especially the first and last, tie directly into the aims of the bioeconomy envisioned elsewhere in this document.

    - The **College of Engineering,** especially the department of **Chemical and Biological Engineering**. The department lists as its research strengths:
        - Applied mathematics
        - Bioscience and engineering
        - Colloids/particle technology
        - Kinetics and catalysis
        - Materials
        - Nanoscale science and engineering
        - Polymers and rheology
        - Systems, modeling and control
        - Reactor modeling and reaction engineering
        - Thermodynamics
        - Transport phenomena

      Of particular interest is the research on catalysis. This research has already given rise to a new biomass process technology, aqueous-phase reforming, which has spun off a new Wisconsin technology company, Virent (see below), and a means to make biodiesel from sugary biomass (see the Traditional Crops channel). New methods of catalysis are critical for extracting value out of platform bioproducts such as syngas and biogas, making this a priority research direction. Equally important to Wisconsin's adoption of biorefining is the rest of the college, from R&D to demonstration and commercialization to the operation of facilities.
    - **University of Wisconsin Technology Enterprise Cooperative (UW-TEC).** UW-TEC is a collaboration between CALS, the College of Engineering and the School of Business that organizes "cooperative ventures where students, faculty, staff and private-sector partners provide in-kind resources to develop a technology to the point of commercialization."
    - **Wisconsin Alumni Research Foundation (WARF).** WARF serves two purposes for UW-Madison: technology transfer and research funding via investment management. WARF handles the patenting and licensing of UW-Madison inventions so that the fruit of the university's research can be realized and commercialized, and routes the funds from that licensing to the university to fund early-stage research. WARF has patented over 1,500 UW inventions and entered into nearly than many license agreements since 1925, and the $800 million it has given has supported more than 50,000 research programs in that time, as well as helping to fund more than 50 campus research facilities. (WARF gave $55.5 million for 1,400 projects last year.) WARF also holds equity in companies that spin off from this research.
- **Other campuses and universities.** While UW-Madison has the most R&D resources of any university in the state, many public and private schools throughout the state represent a wealth of intellectual ability that can be harnessed

to support bioeconomy development. In our interview with Dick Burgess of the McArdle Laboratory for Cancer Research at UW-Madison, he noted that an untapped resource for efforts such as this are the many top-flight researchers trained by the UW system who pursue positions at UW satellite campuses. The following list of departments whose work is related to bioeconomy R&D is by no means exhaustive, but shows the breadth of work being pursued.

- The **University of Wisconsin at Green Bay Department of Natural and Applied Sciences** has strong life science and engineering components, and hosts among other things the **Paper Technology Transfer Center**.
- The **University of Wisconsin at Milwaukee's College of Engineering and Applied Science** hosts centers whose work could be directed in ways very beneficial to Wisconsin's bioeconomy, including the **Center for By-Products Utilization** and **Center for Alternative Fuels**.
- The **University of Wisconsin at Stevens Point College of Natural Resources (CNR)** is one of the top undergraduate programs of its kind in the US, with leading programs in forestry and paper science. CNR has been a critical component in training Wisconsin's pulp and paper workforce and will have a major role to play to facilitate the adoption of the forest biorefinery.
- **Marquette University** in Milwaukee conducts research in many related disciplines, including robust programs in biological sciences and engineering. The university has **Biological and Biomedical Research Institute.**

Private Industry

In the competitive marketplace that faces technology companies, research and development is essential for private companies. There are more biotechnology and biorefining companies in Wisconsin that can be easily catalogued, but a few examples follow to demonstrate the next-level biobased industry players already present in the state.

- **Forage Genetics International**, an Idaho-based company, is Monsanto's exclusive partner in alfalfa-centered biotechnology. FGI has a forage breeding station in West Salem.
- **Genencor** is a California-based company specializing in enzymes, with an emphasis on agri-processing and industrial biotechnology. Genencor has eight worldwide manufacturing facilities, including one in Beloit, Wis.
- **Lucigen** of Middleton focuses on molecular cloning as an avenue for understanding the capabilities of previously inaccessible organisms. Among their areas of focus is developing enzymes that improve ethanol production[1], but Lucigen's unique abilities could benefit anyone pursuing bioprocessing.
- **Monsanto** is a Missouri-based company with dual focuses on seeds/genomics and agricultural productivity, best known for Roundup herbicide. In addition to a Madison office, Monsanto has acquired **Agracetus** of Middleton, a 100,000-sq.ft. R&D facility investigating soybeans, cotton, rice and the nutritional content of plants

[1] http://www.lucigen.com/about/presspage.html

- **Promega** is a Madison-based company whose success is grounded in providing life sciences researchers with cutting-edge tools for their work. A recent agreement with WARF gives Promega earlier access to newly licensable technologies offered by WARF. Promega's services cover a wide swath of biotech endeavors, including plant biotechnology.
- **Virent Energy Systems** of Madison uses a process developed in a UW-Madison lab to convert aqueous solutions of oxygenated compounds into hydrogen, hydrocarbon fuels or any number of other products via a single reactor. Among the biobased feedstocks the company has considered include glycerol, sorbitol, alcohols, whey and sugars from hemicellulose.

Federal Research Facilities
Wisconsin is home to two USDA facilities, both in Madison.

- The **Forest Products Laboratory**, part of the USDA Forest Service, is the nation's leading wood research facility. FPL research extends to all facets of wood use, from solid wood products and structural applications to pulp and paper and recycling. FPL research units include:
    - Center for Forest Mycology Research
    - Center for Wood Anatomy Research
    - Engineered Properties and Structures
    - Building Moisture and Durability
    - Condition Assessment and Rehabilitation of Structures
    - Wood Preservation
    - Statistical Methods in Wood and Fiber Research
    - Fire Safety
    - Timber Demand and Technology Assessment Research
    - Engineering Mechanics and Remote Sensing Laboratory
    - Biodeterioration of Wood
    - Wood Adhesives Science and Technology
    - Performance Engineered Composites
    - Wood Surface Chemistry
    - Chemistry and Pulping
    - Fiber Processing and Paper Performance
    - Institute for Microbial and Biochemical Technology
    - Modified Lignocellulosic Materials
    - Analytical Chemistry and Microscopy Laboratory
    - Paper Test Laboratory

  The forest resource and associated expertise is what most distinguishes Wisconsin from its neighboring states, and the Forest Products Lab is integral to harnessing that advantage.
- The **US Dairy Forage Research Center**, part of the USDA Agricultural Research Service, investigates how to best develop dairy forage systems that serve the food supply, the environment and the animals themselves. Research programs at the center are organized into the following topic areas:
    - Aquaculture

- Bioenergy & Energy Alternatives
- Food Animal Production
- Integrated Farming Systems
- Manure and Byproduct Utilization
- Quality and Utilization of Agricultural Products
- Rangeland, Pasture and Forages

Additionally, the Madison facility hosts the USDA's Cereal Crops Research Unit (formerly the Barley Malt Lab) and Vegetable Crops Research Unit.

It is worth noting that Wisconsin also has a number of entities involved in technology transfer, some of which, such as WARF, have already been mentioned here.

Market Opportunity
The R&D capacity detailed above, which is an limited picture of the R&D capacity available in Wisconsin, is massive. The difficulty in directing those resources toward the same end, however, is equally large.

Taken together, the research capabilities of the UW campuses, the reach of the UW's Extension education and outreach program and the intellectual property capabilities of WARF offer a powerful combination for moving the state forward in virtually any direction it is focused, to say nothing of private research and universities and the national labs. With regard to bioindustry, however, the UW System and Wisconsin as a whole today lack any common purpose or coordinating agency. The educational and research efforts which do exist are small and scattered among numerous departments and institutions. Bioindustry needs are multidisciplinary but efforts are currently stuck within silo structures. Coordinating efforts can realistically be driven only by funding and bioindustry initiatives, to date, have not been a priority.

Robust R&D is the only thing that will permit Wisconsin to develop a "leapfrog" opportunity in bioindustry—a chance to apply novel research findings to cause discontinuous change and instantly reposition the state as a leader in a given field. These opportunities are unpredictable, which is why basic R&D is as important in this arena as applied R&D. Without those kinds of opportunities being developed in the state, Wisconsin will have a greatly reduced chance of taking leadership in technology development, which can be one of the greatest value-adding opportunities in the bioeconomy.

PEST Analysis

Key PEST issues related to this channel deal with the lack of coordination within the state for dealing with the bioeconomy, as well as a lack of funding and sense of urgency.

Political/Legal

+ Wisconsin universities have fostered strong industry relationships.
± Even within the broad world of biorefining, there are competing research agendas.
– There is no coordinating influence shaping biobased industry development in the state.

– Lack of state funding in this area combines with institutional inertia to limit movement toward biobased industry.
– Legislative priorities are not aligned with biobased industry development at UW.

Economic

+ Commercialization could facilitate long-term funding opportunities.
± Going forward, there will be increased competition for the best thinkers of the bioeconomy, which favors the entities that are willing to pay to pursue them and penalizes the entities that are not proactive about retaining them.

Social

+ A growing bioeconomy creates opportunities for those whose scientific and technical educations cause them to leave Wisconsin to find work in their field.
+ The bioeconomy presents a significant opportunity to engage researchers at UW satellite campuses who are perfectly positioned to contribute to the state's exploration of biorefining possibilities while also bringing a diverse understanding of the needs and capabilities of various Wisconsin regions.
– UW System's research and education mission limits its ability to help with commercialization issues and limits the development of an entrepreneurial culture.

Technological

+ Wisconsin sees "spillover" benefits from having UW System, private industry and federal facilities so closely located.
+ Wisconsin's R&D entities are extremely capable.
± Research of pre-commercial technologies can be conducted with little regard for intellectual property concerns.
± Research directions are driven by funding availability.
– Intellectual property concerns can prevent any public/private, private/private or even public/public partnership from forming.
– R&D and education efforts in biobased industry are narrowly focused and scattered in numerous departments and colleges.
– Biobased industry needs are multidisciplinary, which conflicts with traditional UW silo structure.
– There is a lack of communication going both from the labs to industry, which should deal with the research that is currently being done, and from industry to the lab, which should deal with the research that industry wants to see.
– Ideas worth being commercialized are not always recognized.

Wisconsin's R&D sector has everything it needs to pursue the development of the bioeconomy in earnest, but the sector suffers from a lack of organization, lack of coordination with state efforts, and an overall lack of funding. Until there is real leadership in this sector, the state's bioeconomy effort will not only be stalled, it may be fatally wounded by the loss of R&D scientists to regions where the work in this area is more valued.

Regional Strength in Channel Industries

One of the essential components of a successful bioindustry development plan in Wisconsin will be its ability to reach to all corners of the state and capitalize on the specific resources and industries that make different intra-state regions unique. The maps we have shown throughout this document highlight the location of various feedstocks and processing sites across the state; however, none of these maps indicates which regions might be the most competitive within the state at pursuing activities in a particular biobased industry channel.

To begin to answer this question, we analyzed Wisconsin's regional distinctiveness in a number of industries using the location quotient tool. As described in the Briefing Paper, a location quotient is simply the ratio between a chosen economy (in this case, a particular region within the state) and a reference economy (in this case the U.S.). In a region/U.S. comparison, for example, wherever a region's concentration of employees is greater in a particular industry than the concentration of employees in that industry in the U.S., the location quotient is above 1.0. Where a region's concentration is below that of the U.S., the location quotient is below 1.0. A location quotient above 1.0 indicates that it is more likely in a particular state region than in the country as a whole that a person will work in a given industry; for instance, a location quotient of 6.0 means that someone in Wisconsin is six times as likely to work in that industry as in the U.S. Thus location quotients provide a fairly good measure of the state's local distinctiveness in particular industries, and also its potential for growth in those industries.[1]

To get a sense of regional distinctiveness in the industries making up the biobased channels we have identified, we first assigned industries to channels. A full list of the industries included in each channel can be found in Table B at the end of this section. We then aggregated the employment numbers for those industries, and came up with the share of employees within each region who work within that particular channel. For instance, for the Forest Biorefinery channel, we added up the employees in each region who work in the following industries:

- Forest nurseries, forest products and timber tracts
- Agriculture and forestry support activities
- Pulp mills
- Paper and paperboard mills

We then determined what share of each region's employees work in these four industries combined, compared that number to the national share of employees in those industries, and thus came up with the location quotient for Forest Biorefinery for each region in the state.

Because location quotients are based on employment data, we decided to define the state's regions using the Wisconsin Workforce Development Areas (WDAs), whose boundaries are based on the state's basic employment and workforce patterns. There are eleven WDAs in Wisconsin; a map of the regions can be found in Figure A.

[1] This is of course a simplification, as demand varies regionally.

Findings

Table 2 shows our analysis of regional location quotients in each channel, using the U.S. as a comparison region. We have highlighted each place that an LQ came in over 1.5, indicating regional distinctiveness in that particular channel. For example, Region 4, the Fox Valley area, shows regional distinctiveness (an LQ of 5.3) in the Forest Biorefinery channel, meaning that a person living in the Fox Valley is 5.3 times more likely to be employed in this channel than a person living in the U.S. generally. Regions 5 and 6, which are adjacent to the Fox Valley, are also very strong in the Forest Biorefinery channel. This information, though hardly shocking, should point policymakers in the direction of this part of the state when deciding where to target policies for Forest Biorefinery development.

Other conclusions from this table include the following:

- Like Forest Biorefinery, Wood Residues is a strong channel in the Fox Valley area, but also extends further north into Region 7, and further west into Regions 8 and 9, meaning that policies in this area might be crafted to include cross-border trade with Minnesota and Iowa.
- Western Wisconsin (Regions 7-9 and Region 11) is most distinctive in the Farm Manure Management channel, though the Bay Area (Region 5) also makes a strong showing here.
- These same areas – the western part of the state and Region 11 – also show distinctiveness in industries related to Traditional Crops and New and Dedicated Crops.
- Many regions in the state come across as distinctive in the Chemical channel, especially Region 1, including Racine, and Regions 3-5, north of Milwaukee. This finding is most likely related to the presence in these regions of large plastics and solvents manufacturers, such as S.C. Johnson in Racine. These are potential end-users of biobased chemicals more than they are potential inventors of biobased chemicals; however, their importance to the chemical channel is still fundamental, and the fact that the state is generally strong in this area is significant.
- The LQ for the research and development channel is not particularly high in any region of the state. However, this means only that there is not a concentration of people working in this channel in any region as compared to the U.S., not that there is not strong research and development *potential* or *quality* in a particular region. Put more simply, the international reputation of the UW-Madison is not reflected in LQ data. In this channel more than the others, quality rather than quantity may be the most important economic development factor. We expect an ongoing scan of UW System biorefining activity, organized by Greg Wise of UW Extension, to shed far more light on this channel than the LQ analysis can.

Readers will notice that within the state, the most populous region – Region 2, made up only of Milwaukee – has no LQs over 1.0. Its highest LQ is in Industrial Waste Streams, probably due to the number of food processing facilities in that area. This absence of distinctiveness may be explained in several ways: First, Milwaukee is so populous that the share of workers in any given industry in that city will be lower than if the same industry were located in a less populous region. Second, it is an urban area, and does not contain any of the agricultural or forest land that makes the rest of the state so strong in these channel activities. Third, many of the manufacturing and processing facilities that were once located inside Milwaukee's borders have moved outside the city. That Milwaukee does not show up as distinctive in the feedstock, processing, or end product manufacturing that we have grouped under each channel should not, however, turn policymakers away from that area when devising a bioeconomy strategy. On the contrary, the fact that Milwaukee is so populous means that it will be the region of the state most likely to actually use the bioenergy, biofuels, and bioproducts being created by these industries.

Table 1: Location Quotient by Region and Cluster (US as comparison area)

	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7	Region 8	Region 9	Region 10	Region 11
CHEM	2.1	0.9	2.4	2.9	2.3	0.9	1.2	1.7	2.1	1.5	0.9
CR	1.5	0.3	0.8	1.5	1.5	1.8	1.8	2.9	3.4	1.4	2.9
FB	0.3	0.1	0.1	5.3	4.1	5.9	1.3	0.7	0.3	1.6	0.5
WR	0.9	0.7	0.8	3.2	2.7	4.0	4.3	1.5	1.8	1.1	0.8
IW	1.4	1.0	1.0	2.0	2.0	2.1	1.8	1.7	1.3	1.1	1.3
MM	0.9	0.5	0.6	1.4	2.2	1.7	2.7	3.3	2.8	1.5	3.1
NC	1.3	0.2	0.6	1.1	1.2	1.4	1.6	2.3	2.4	1.4	2.2
TC	1.3	0.3	0.6	1.2	1.3	1.5	1.6	2.3	2.5	1.5	2.4
UW	1.1	1.4	0.7	0.9	1.0	1.0	1.1	1.2	1.1	0.8	1.0

Location quotient data is imperfect, in that all it shows is the current concentration of workers in a particular industry or set of industries and in a particular region, as compared to the concentration of workers in that industry in the U.S. However, it does give us a very broad picture of what parts of the state might be expected to be most productive, and show most local distinctiveness, in the set of industries that make up a bioindustry channel. When considering policies directed at strengthening these channels, the state can use this information about local distinctiveness as a guide to where to target investments, incentives, and other policy mechanisms.

Figure 1: Map of Wisconsin's Workforce Development Areas

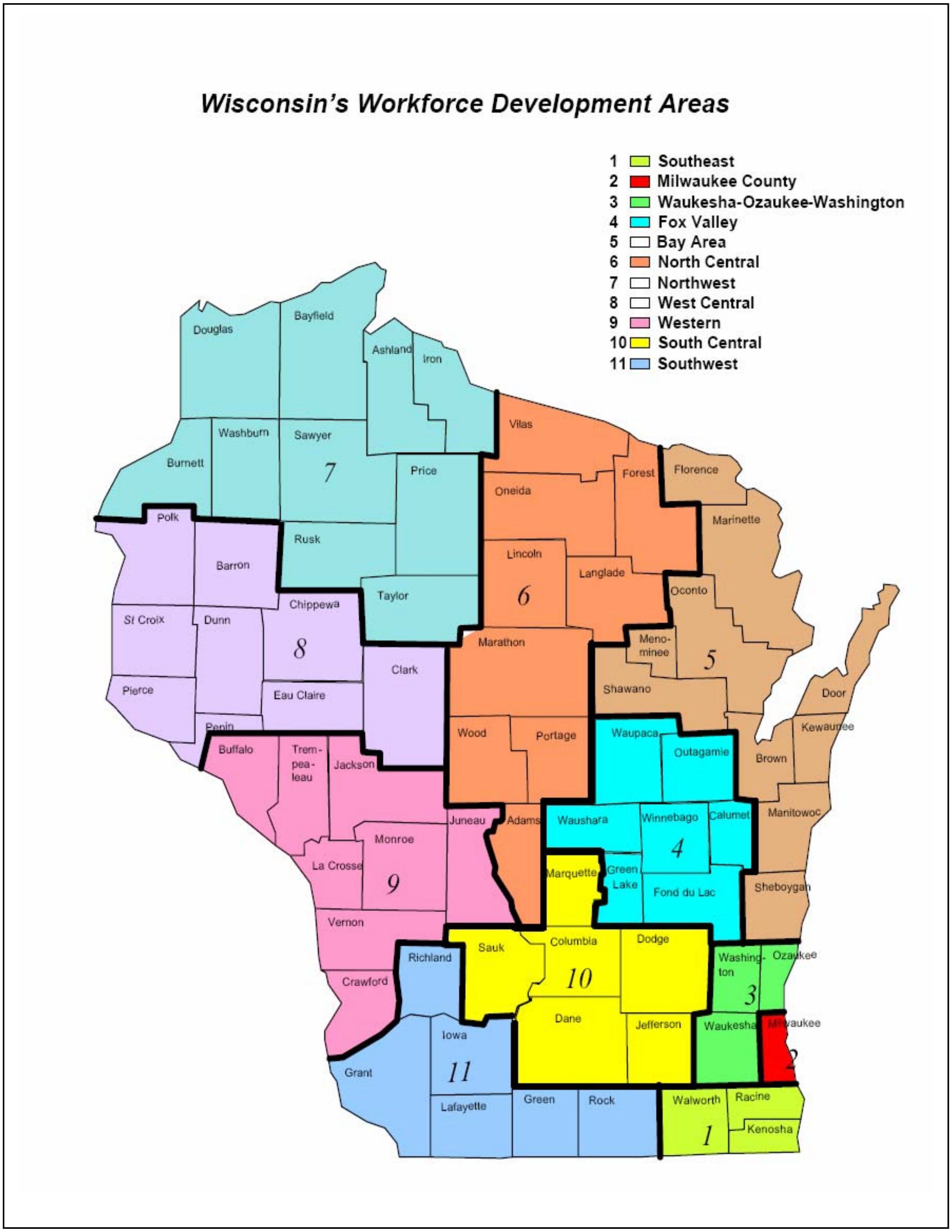


Table 2: List of Industries Included in Each Channel for Purposes of LQ Analysis

Biobased Chemicals (CHEM):

Paperboard container manufacturing
Flexible packaging foil manufacturing
Coated and laminated paper and packaging materials
Coated and uncoated paper bag manufacturing
Die-cut paper office supplies manufacturing
Envelope manufacturing
Stationery and related product manufacturing
Sanitary paper product manufacturing
All other converted paper product manufacturing
Manifold business forms printing
Books printing
Blankbook and looseleaf binder manufacturing
Commercial printing
Tradebinding and related work
Asphalt paving mixture and block manufacturing
Asphalt shingle and coating materials manufacturing
Petroleum lubricating oil and grease manufacturing
All other petroleum and coal products manufacturing
Petrochemical manufacturing
Industrial gas manufacturing
Synthetic dye and pigment manufacturing
Other basic inorganic chemical manufacturing
Plastics material and resin manufacturing
Synthetic rubber manufacturing
Cellulosic organic fiber manufacturing
Noncellulosic organic fiber manufacturing
Nitrogenous fertilizer manufacturing
Phosphatic fertilizer manufacturing
Pesticide and other agricultural chemical manufacturing
Pharmaceutical and medicine manufacturing
Adhesive manufacturing
Soap and other detergent manufacturing
Polish and other sanitation good manufacturing
Surface active agent manufacturing
Toilet preparation manufacturing
Custom compounding of purchased resins
Photographic film and chemical manufacturing
Other miscellaneous chemical product manufacturing
Plastics packaging materials, film and sheet
Plastics pipe, fittings, and profile shapes
Laminated plastics plate, sheet, and shapes
Plastics bottle manufacturing
Resilient floor covering manufacturing
Plastics plumbing fixtures and all other plastics products
Foam product manufacturing
Tire manufacturing
Rubber and plastics hose and belting manufacturing
Other rubber product manufacturing
Abrasive product manufacturing
Secondary processing of copper
Secondary processing of other nonferrous
Electroplating, anodizing, and coloring metal
Motor vehicle body manufacturing
Sign manufacturing
Wood kitchen cabinet and countertop manufacturing
Nonupholstered wood household furniture manufacturing
Institutional furniture manufacturing
Wood office furniture manufacturing
Custom architectural woodwork and millwork
Upholstered household furniture manufacturing
Metal household furniture manufacturing
Other household and institutional furniture
Other basic organic chemical manufacturing
Paint and coating manufacturing
Printing ink manufacturing
Lime manufacturing
Fertilizer, mixing only, manufacturing

Crop Residues (CR):

Tobacco stemming and redrying
Cellulosic organic fiber manufacturing
Oilseed farming
Grain farming
Vegetable and melon farming
Maintenance and repair of farm and nonfarm residential structures
Farm machinery and equipment manufacturing
Gasoline stations
Paint and coating manufacturing
Fruit farming

Forest Biorefinery (FB):

Forest nurseries, forest products, and timber tracts
Agriculture and forestry support activities
Pulp mills
Paper and paperboard mills

Wood Residues (WR):

Logging
Sawmills
Wood preservation
Reconstituted wood product manufacturing
Veneer and plywood manufacturing
Engineered wood member and truss manufacturing
Wood windows and door manufacturing
Cut stock, resawing lumber, and planing
Other millwork, including flooring
Wood container and pallet manufacturing
Prefabricated wood building manufacturing
Miscellaneous wood product manufacturing
Surface-coated paperboard manufactuing
Wood kitchen cabinet and countertop manufacturing
Nonupholstered wood household furniture manufacturing
Institutional furniture manufacturing
Wood office furniture manufacturing
Custom architectural woodwork and millwork
Building material and garden supply stores
Paperboard container manufacturing
Coated and laminated paper and packaging materials
Coated and uncoated paper bag manufacturing
Die-cut paper office supplies manufacturing
Envelope manufacturing
Stationery and related product manufacturing
Sanitary paper product manufacturing
All other converted paper product manufacturing
Blankbook and looseleaf binder manufacturing
Asphalt paving mixture and block manufacturing
Asphalt shingle and coating materials manufacturing
Cellulosic organic fiber manufacturing
Forest nurseries, forest products, and timber tracts
Agriculture and forestry support activities
Pulp mills
Paper and paperboard mills
Maintenance and repair of highways, streets, bridges, and tunnels
Manufactured home, mobile home, manufacturing
Lime manufacturing

Industrial Wastestreams (IW):

Spice and extract manufacturing
All other food manufacturing
Soft drink and ice manufacturing
Breweries
Wineries
Distilleries
Cigarette manufacturing
Other tobacco product manufacturing
Food and beverage stores
Animal, except poultry, slaughtering
Fertilizer, mixing only, manufacturing
Other oilseed processing
Fats and oils refining and blending
Wet corn milling
Soybean processing
Breakfast cereal manufacturing
Sugar manufacturing
Tobacco stemming and redrying
Pulp mills
Paper and paperboard mills
Building material and garden supply stores

Farm Manure Management (MM):

Cattle ranching and farming
Animal production, except cattle and poultry and eggs
Animal, except poultry, slaughtering
Fertilizer, mixing only, manufacturing
Building material and garden supply stores
Poultry and egg production
Agriculture and forestry support activities

New and Dedicated Crops (NC):

Tree nut farming
Cotton farming
Sugarcane and sugar beet farming
Poultry and egg production
Other oilseed processing
Fats and oils refining and blending
Tobacco stemming and redrying
Oilseed farming
Grain farming
Vegetable and melon farming
All other crop farming
Maintenance and repair of farm and nonfarm residential structures
Other basic organic chemical manufacturing
Paint and coating manufacturing
Printing ink manufacturing
Lime manufacturing
Hand and edge tool manufacturing
Farm machinery and equipment manufacturing
Gasoline stations
Fruit farming
Dog and cat food manufacturing
Other animal food manufacturing
Animal production, except cattle and poultry and eggs
Agriculture and forestry support activities
Fertilizer, mixing only, manufacturing

Traditional Crops (TC):

Oilseed farming
Grain farming
Vegetable and melon farming
All other crop farming
Maintenance and repair of farm and nonfarm residential structures
Wet corn milling
Soybean processing
Other basic organic chemical manufacturing
Paint and coating manufacturing
Printing ink manufacturing
Lime manufacturing
Hand and edge tool manufacturing
Farm machinery and equipment manufacturing
Gasoline stations
Fruit farming
Dog and cat food manufacturing

Other animal food manufacturing
Animal production, except cattle and poultry and eggs
Agriculture and forestry support activities
Fertilizer, mixing only, manufacturing

University of Wisconsin (UW)

Other educational services
Hospitals
State & Local Education

Appendix A

Wisconsin Biobased Initiative

Chemical Industry Report

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Disclaimer: This report represents the views and opinions of the authors not Argonne National Laboratory. No resources from Argonne National Laboratory were used to prepare this report.

Executive Summary

Evaluation of opportunities in the biobased industry requires consideration of feedstocks, products, and process technologies. As part of the Wisconsin Biorefining Development Initiative, the Energy Center of Wisconsin recently completed a broad study of the available biobased feedstocks, potential biobased products and relevant biorefining processes. In order to present a report that provides valuable insight to the commercial opportunities, we focused on those feedstocks, products and technologies that currently *or* could have a significant impact, i.e. 1) they are already in significant use and/or are growing rapidly, 2) they have a potential for large use or 3) the products have wide commercial applicability. We reviewed several feedstocks, including 1) agriculture: corn, oil seeds, and other crops; 2) forest products; and 3) residues and wastes. We considered fuel, chemical, and feed products as well as synergies between these products.

The primary focus of this report is on larger volume products where Wisconsin has competitive advantages due to synergies in the supply chain or the cost/volumes of the biobased feedstocks. These products compete on a cost basis where raw materials and energy are typically the largest operating costs. This is a short scoping study and an initial assessment. Our primary conclusions and recommendations are:

1. Wisconsin is a mixed agriculture state but unlike its agricultural mid-western neighbors, it also has a preeminent forest products industry.
2. Three feedstocks: corn, forest products (pulp and paper and forest residues) and soybeans are the only ones appropriate for building a biobased chemicals industry for the next decade.
3. During the past few years biobased liquid fuel products namely: ethanol and biodiesel (fatty acid methyl esters) have been the base drivers for the growth of the industry. In terms of volume, the liquid fuel market is about tenfold larger than chemical products. Thus building a base for these fuels from conversion of the state's competitive resources is a critical part of the strategy for building a biobased chemicals industry.
4. For corn, dry milling technology should be primary path. The potential synergy between the state's dairy industry's feed needs and the wet DDGs from the dry mills should be actively developed and exploited. This synergy can differentiate Wisconsin from the other Midwestern corn growing states and make it very competitive.
5. The initial growth product should be fuel ethanol (the state already has 200 million gallons/year production) followed by opportunistic addition of other biobased chemicals.
6. Organic acids namely: acetic, lactic and its derivatives (PLA and solvents) and polyols (1,3-propanediol) would be some of the prime targets.
7. Biodiesel from soybean oil has a strong growth potential. For Wisconsin, developing a synergy between the state's dairy feed needs and the soybean meal and developing use for byproduct glycerol would be important to make it competitive.
8. Gasification is the preferential route with higher lignin content biomass and biomass-derived feedstocks. Wood, residues and black liquor from forest product processing are the primary feedstocks that fit this category.

9. Developing syngas fermentation/bioprocessing technologies to make ethanol and organic acids such as acetic acid are the recommended technology path for the long term outlook. Given Wisconsin's preeminent position in P&P and other forest products this product and technology path would be very important for its long term competitiveness in the bio based chemicals industry.

10. In order to develop a biobased chemical industry, Wisconsin will need to identify and partner with end users. Advantages to consider in the future include carbon dioxide credits to meet Kyoto Accords for European based companies.

11. Wisconsin has a strong academic and National Laboratory sectors. Many of the technologies require a skilled workforce. Fostering of R&D and training programs in the relevant technologies will help provide the workforce for the biobased industry. In addition, a strong R&D presence will help Wisconsin develop higher-valued specialty products.

Creating the Wisconsin Biorefinery Industry

Biomass, the original source for fuels and energy, has seen a sharp increase in interest. The major economic and political driving forces are:

- *Stable Energy Supply* – Decreased dependence on imported petroleum.
- *Environmental* – Sustainable use of resources and reductions in greenhouse gas emissions and other pollutants.
- *Socioeconomic* – Growth of rural economies including job creation and strong markets for forest and agricultural products.

Evaluation of opportunities in the biobased industry requires consideration of feedstocks, products, and process technologies. As part of the Wisconsin Biorefining Development Initiative, the Energy Center of Wisconsin (2005) recently completed a broad study of the available biobased feedstocks, potential biobased products and relevant biorefining processes. In order to present a report that provides valuable insight to the commercial opportunities, we focus on those feedstocks, products and technologies that currently *or* could have a significant impact, i.e. 1) they are already in significant use and/or are growing rapidly, 2) they have a potential for large use or 3) the products have wide commercial applicability. We review several feedstocks, including 1) agriculture: corn, oil seeds, and other crops; 2) forest products; and 3) residues and wastes. We consider fuel, chemical, and feed products as well as synergies between these products.

In this report, we summarize the critical factors for identifying opportunities for commercialization of biobased products and select a few targets that Wisconsin has competitive advantages. We consider two classes of products: 1) larger volume or commodity-based products and 2) higher valued specialty products. In general, we focus on biobased products where Wisconsin has economic advantages.

The primary focus of this report is on larger volume products where Wisconsin has competitive advantages due to synergies in the supply chain or the cost/volumes of the biobased feedstocks. These products compete on a cost basis where raw materials and energy are typically the largest operating costs.

A second set of economic opportunities are based on higher-valued specialty products. Cost of feedstocks and process synergies are not as critical as intellectual property and market knowledge in specialty products. Wisconsin has strong academic and laboratory sectors that could develop new businesses that partner with regional industry. The new businesses tend to develop around the "idea generators", if capital and business services are available. The cost of feedstock and labor are not typical drivers in this new business development. These opportunities will not be reviewed in detail in this report.

Both opportunities depend on access to a skilled work force in bioprocessing and chemical engineering, where Wisconsin has distinct advantages over other regions of the U.S. and international competition. Both opportunities require access to the capital markets, a subject that is beyond the scope of this report.

Factors for Success of the Biobased Industry

The scope of this report is to identify opportunities to convert Wisconsin's biobased feedstocks to fungible products. The basis of the analysis is to select feedstocks and products that could attract capital to become successful commercial operations. To be successful the biobased industry needs to meet most of the following criteria.

- **Feedstocks – (Economical raw materials)**
  - Large enough in volume and high enough in density where the state may have a competitive advantage.
  - Have an infrastructure for production, collection/transportation, commerce and use.
  - Have an existing or related industry for the feedstock or food/feed use of co-products or byproducts.
  - Relatively uniform in composition and not too heterogeneous.
- **Products – (Markets)**
  - Cost benefits to replace or supplement existing products
  - Renewable resources replacing petrochemical feedstocks.
  - Environmental and regulatory drivers.
  - Superior/high performance.
  - Supply chain to sell the product
- **Technologies – (Efficient and economical processes)**
  - Not dependent on unproven or uneconomical technologies
  - Established or available vendor market
  - Unique positions in intellectual property for specialty products
- **Financials – (Capital and O&M)**
  - A defined supply chain to justify capital investment
  - Risk reduction available from Federal or State tax incentives.

In these report we focus on the feedstocks and products with the most commercial promise. ECW (2005) has already reviewed most of the relevant technologies, and we only review technologies not already covered in the ECW analysis. The financial factors are beyond the scope of this technical review.

Feedstocks

Wisconsin is a mixed agriculture state. Row crops, primarily corn and soybeans, dominate the southern part of the state, similar to Illinois and Iowa. Unlike its agricultural Midwestern neighbors, Wisconsin also has a strong forestry industry that is more similar to the Southeastern and Northwestern regions of the U.S.

Currently agriculturally derived feedstocks provide the bulk of the biomass derived liquid fuel products using catalytic and process technologies. Viable utilization of heterogeneous biomass feedstocks requires that all the fractions that are not converted to the energy product be utilized internally or processed and sold as co-products of value, leaving nothing to waste. This is a very important and complex feature for both the current agriculturally-based feedstocks and products and any future feedstocks or products.

Corn

Corn is the largest cereal crop grown in the world, and is used primarily for food and feed. Historically, the corn yield has steadily increased due to better biotechnology and agronomic practices. The year-to-year production depends on various factors such as weather, the acreage planted and harvested as well as set aside due to price and production incentives. The primary usage of corn is animal feed followed by food products including sweeteners. Almost 20 % of the U.S. corn crop is exported. About 15% of the corn has been used for wide variety industrial products, including ethanol (~11 % of the corn crop). This trend is changing as fuel ethanol production and usage is increasing.

In Table 1 and Figure 1 we highlight Wisconsin counties with high corn production (>18,000 BU/square mile). This Corn Belt spans the southern region of the state and represents a real opportunity for a feedstock with a sufficient volume and density to build a biobased products industry. The seven highlighted counties produce about 140 million BU/year of corn (almost 40 % of Wisconsin total). From this region, corn can provide about 4.5 billion pounds of fermentable sugar, a very sizable volume over about 6000 square miles with an average transportation distance of less than 60 miles. Corn is an excellent feedstock to build a dry mill-based industry across the southern region of Wisconsin.

Table 1: Counties with high density corn production

County	Production (million BU)	Land Area (sq miles)	Density (BU/sq mile)
Rock	23.1	721	32061
Lafayette	18.4	634	29009
Green	13.8	584	23630
Walworth	12.4	555	22276
Dane	24.7	1202	20551
Grant	21.8	1148	18948
Jefferson	10.5	557	18923
Columbia	14.2	774	18390
Region	**138.9**	**6174.0**	**22493**

Source ECW (2005)

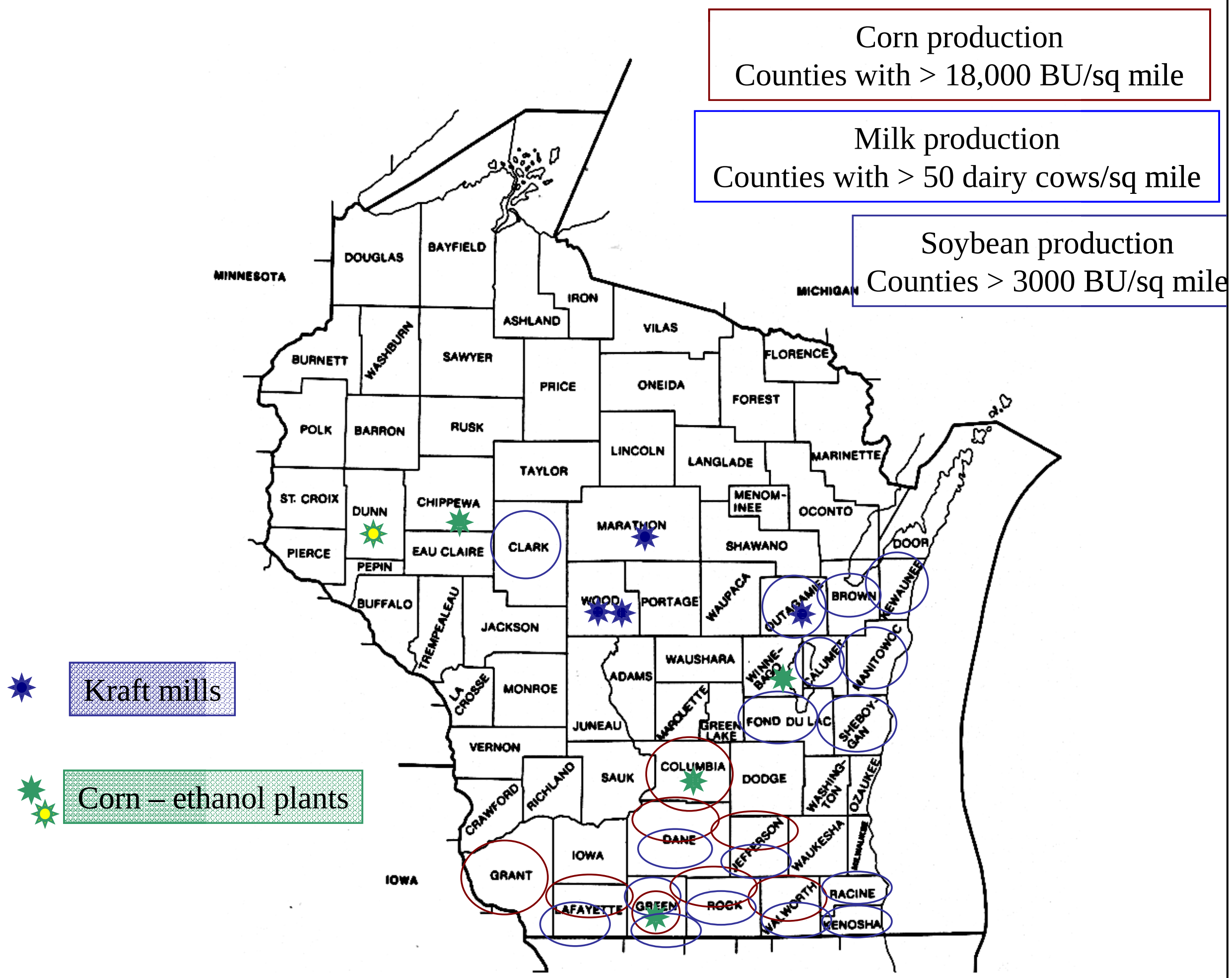

Figure 1: County map noting locating of highest volume corn and soybean production as well as location of ethanol plants and Kraft mills.

Oil seeds and fats

The major oilseeds crops are soybean (~21 % oil) from the temperate and semi-tropical regions (mainly US and Brazil), rapeseed (canola ~42 % oil) from the cool temperate regions (mainly Canada and Europe) and palm (~50 % oil) from the tropical regions.

The primary purpose of the oilseed crops are oil and protein for human and animal consumption, and industrial products such as soaps and detergents/surfactants, and residual cake that are used for animal feed. Recently, a small but increasing fraction of the oil is being used for energy, i.e. biodiesel production using catalytic and process technologies.

Soybeans

In Table 2 and Figure 1 we highlight counties with high soybean production (>3,000 BU/square mile). Almost overlapping the Corn Belt, the soybean belt spans the southern region of the state and represents a real opportunity for a feedstock with a sufficient volume and density to build a biobased products industry. The eight highlighted counties produce about 18 million BU/year of soybeans (about 1/3 of the Wisconsin total). Soybeans from this region provide about 0.20 billion pounds of oil, a sizable volume over about 5000 square miles with an average transportation distance of less than 60 miles. Soybeans offer an opportunity to build a biodiesel industry in the southern region of Wisconsin.

Table 2: Counties with high density soybean production

County	Production (million BU)	Land Area (sq miles)	Density (BU/sq mile)
Rock	3.82	721	5302
Lafayette	2.69	634	4246
Walworth	2.07	555	3728
Green	2.17	584	3716
Racine	1.18	333	3542
Kenosha	0.92	273	3383
Dane	3.68	1202	3062
Jefferson	1.69	557	3034
Region	**18.22**	**4858**	**3751**

Source ECW (2005).

Forest products

Wisconsin has a well-established strong forest products industry. It is ranked first in pulp and paper production in the U.S. with six integrated pulp and paper (P&P) mills and output of 5.5 million tons of paper and 1.1 million tons of paperboard annually (ECW, 2005). In addition, the estimated collectable forest residue is 1.7 million tons @ ~$15/ton (3.4 billion pounds). Other potential feedstocks include: paper mill residues: 1.7 million tons (3.4 billion pounds) – (25% of solids are fibers, 25% waste clays etc. 50% water), Sawdust: big lumber industry but sawdust volumes are unknown. This is the most impressive feedstock and industry base and the state's database has numerous reports on the volumes and statistics of this industry.

Generally, this industry is self sufficient in biomass energy for its power and heat needs. Integrated P&P mills are large operations that chemically separate the cellulose fiber for paper from wood and use the separated lignin and other components (black liquor) in Tomlinson recovery furnaces/boilers for pulping chemical recovery as well as heat and power.

Recent advances in gasification technologies for both the black liquor gasification (BLG) as well and wood and forest residue gasification will enable this industry and feedstock base to become a surplus producer of energy and therefore potential major supplier for liquid fuels and chemicals. The state energy authority has conducted an impressive analysis of the advances in the BLG and wood gasification technologies ECW (2005). Later in this report we review some of the liquid fuel products (ethanol, mixed alcohols) and chemicals (organic acids) that would become feasible via bioprocessing or chemical conversion routes. We believe that developing and implementing these technologies could make Wisconsin a major long term player in the chemical industry.

Feedstocks that do not meet the targets for commercial development

Other grain products

Other grains are produced in much smaller volumes in Wisconsin. We reviewed three crops: barley, oats, and wheat. These crops have distinct disadvantages in comparison to corn, including highest and average density and total production volumes (Table 3). They could provide supplemental feedstock to a biobased industry developed with corn, but it is unlikely that they will be the drivers for new commercial development in biobased fuels and chemicals.

Table 3: Production of grains

Crop	Total Production (million BU)	Peak County Density (BU/sq mile)	Average Density (BU/sq mile)
Barley	1.27	129	62
Oats	13.6	1004	284
Wheat	12.2	1969	416
Corn	***353.0***	***32061***	***7745***

Source ECW (2005).

Other oilseeds and fats

Production of canola and other oil seeds is very small, and would require a political mandate to develop the infrastructure. In addition, it would require displacement of other agricultural sectors, most likely forestry. Therefore, we do not discuss other oil seeds in more detail. Other feedstocks have logistic problems such as disperse distribution that would require significant costs to collect (e.g. waste cooking oil – 100 million pounds/year) or have alternative markets that far exceed their value in the biobased fuel and chemicals markets (e.g. beef tallow – 180 million pounds/year for edible tallow, soaps, etc.)

Wastes

Wastes are distributed and do not represent a strong opportunity for Wisconsin. For example, we reviewed the opportunities for anaerobic digestion in pulp mills (Table 4). The largest plant could produce only about $1.1 M in revenue as biogas or about 1.8 million gallons of ethanol assuming complete conversion of the feedstock. Use of all of the biogas in the state pulp mills would produce less ethanol than one dry grind mill.

As another example, Wisconsin produces about 160,000 tons/year of whey which contains about 58,000 tons of fermentable lactose. If all of Wisconsin's lactose was fermented to ethanol, it would produce about 8 million gallons, less than one dry grind mill. Due to the disperse distribution of this material, lactose fermentation is not considered economically feasible at this time.

Therefore we do not discuss conversion of wastes to products in any more detail. Waste utilization is more suitable for providing onsite heat and power.

Table 4: Wisconsin Natural Gas Use and Potential Biogas Potential in Pulp Mills

400 BCF	Approximate state use of natural gas
400 E6 MM BTU	Approximate state use of natural gas
2.5 E6 MM BTU	Total biogas potential from anaerobic digestion
0.62 %	Percentage of state natural gas that could be generated by anaerobic digestion
$12,310,213	Total revenue at $5 million BTU "wellhead" price by anaerobic digestion
$1,100,000	Revenue for the largest plant - Georgia Pacific-GB-West (Green Bay)
1.8 million gallons	Conversion of biogas from largest plant to ethanol
21 million gallons	Conversion of all biogas to ethanol

Sources – Natural gas use from EIA (2005), anaerobic digestion from (ECW, 2005), conversion to ethanol based on syngas fermentation from Snyder (2005a).

Agricultural residues

Agricultural residues such as corn stover are receiving substantial press recently as a source of cellulosic ethanol. These processes will not be competitive with corn grain alcohol for several years. In the near to mid-term, the state has available corn grain, a more economical and efficient feedstock. Currently, cellulosic ethanol represents ~0.025 % of grain ethanol production. R&D is focused on 1) producing fermentable sugars from cellulose (Mosier, 2005) and 2) fermenting mixed sugars to ethanol (Dien, 2003). Wisconsin's universities and national laboratories should remain abreast of R&D opportunities. The 2005 Energy Bill calls for tripling the R&D budget by FY2008, with a major emphasis on cellulosic ethanol. Wisconsin should remain cognizant of subsidies and incentives for producing cellulosic ethanol

Long term feedstocks

In the longer term, the future expansion of biomass to liquid fuels can only come from lignocellulosic feedstocks and the ones that may significantly contribute are (Perlack 2005):

- Collectable large volume agricultural residues – e.g. corn stover
- Forest product and pulp mill residues
- Energy crops – specifically trees (e.g. poplar) and switchgrasses

These feedstocks are the structural components of the plants/trees and are inherently recalcitrant to biological degradation and conversion. Furthermore, they are very heterogeneous in both structure and components, which generally comprise of glucans (cellulose – C6 sugar polymers) xylan (hemicellulose – C5 sugar polymers), lignin (complex mix of condensed oxygenated aromatic polymers) and small amounts of other components such as proteins, pectins and others. From an energy conversion viewpoint, lignin is more reduced than the glucans and xylans and has the higher energy content per unit mass, and in wood and forest products the lignin often has 50% or more of the energy content.

Opportunities with Wisconsin's feedstocks

We believe that three feedstocks meet the criteria for Wisconsin to develop a biobased products industry over the next decade. These feedstocks have sufficient production volume, density, and infrastructure to provide economical raw materials.

- Corn grain
- Soybean
- BLG and forest product residues

The corn and soybeans are large opportunities in the southern region and forest products are an even larger opportunity in central and northern Wisconsin.

Products

Biobased chemical products that have significant growth potential over the next 10 years

During the past few years biobased liquid fuel products namely: ethanol and biodiesel (fatty acid methyl esters) have been the base drivers for the growth of the industry. In terms of volume the liquid fuel business is about tenfold larger than the chemical products. Thus building a base for these fuels from conversion of the state's competitive resources is a very important part of the strategy for building a biobased chemicals industry. Once this base begins to be built, the chemicals that have significant growth potential can be added on to the existing production plants or plants can be converted to the production of these chemicals. We have highlighted below those we believe have very significant growth potential over the next 10 years and have a bio/process technology path for its manufacture.

Ethanol

Use of ethanol as a motor fuel as is or as an additive to gasoline is well known and has been practiced for over 100 years in many parts of the world. The amounts produced and used have changed over time and as petroleum derived liquid fuels became dominant after the Second World War, ethanol usage declined. Recently, ethanol is making a comeback and currently it is the primary biomass-derived liquid fuel, mainly derived from two agricultural feedstocks corn and sugarcane. Ethanol accounts for close to 3 % of world gasoline use. The U.S. and Brazil are the primary producers.

In 2004, ~3.5 billion gallons of ethanol was produced in the U.S., almost entirely from corn. Since the mid-1980s ethanol production has steadily grown with the support from the federal excise tax credit of 52 cents / gallon of ethanol. In recent years the rate of growth in the U.S. has accelerated due to: a) decline and phase out of methyl tertiary butyl ether (MTBE) as a gasoline oxygenate because of its environmental problems, b) state-wide ethanol mandates, c) increased cost of petroleum, d) tax support incentives that are expected to be continued over a long period. The 2005 Energy Bill further mandates an increase to 7.5 billion gallons/year. Farmer cooperatives account for most of this increase in production. In the past few months, the price of ethanol has decoupled from gasoline and is actually selling below gasoline prices, even without the tax credit.

In Table 5, we summarize current and potential ethanol utilization in Wisconsin. If Wisconsin adopts a 10 % ethanol fuel mandate, this will be a strong driver for growth of the industry to meet internal demands. Just from corn production, Wisconsin can meet a 10 % ethanol mandate and still grow significantly as an ethanol exporter. In Table 6, we estimate percent utilization of corn to produce targeted ethanol levels. Considering current corn conversion to ethanol, direct corn exports, and partnering with the animal feed industry, 50 % utilization is conceivable. At 500 million gallons/year production, Wisconsin would be a substantial ethanol exporter, but not large enough to overwhelm the 7.5 billion gallon/year market in 2012.

Table 5: Ethanol-blended fuel use in Wisconsin

Fuel (million gallons/year)	
2520	Motor gasoline use
1079	Ethanol blended fuel use
108	If blend averages 10 %ethanol
252	Ethanol use with proposed10 % ethanol mandate
144	Additional ethanol usage with 10 % mandate
210	Current ethanol production capacity

Sources – Fuel use in Wisconsin reported by the Federal Highway Administration (EIA, 2005), proposed E10 ethanol mandate reported by the Wisconsin State Journal (2005), ethanol production capacity reported by Ethanol RFA (2005).

Table 6: Potential annual ethanol production from corn

% of Corn Crop	Corn (millions BU)	Ethanol (millions gallons)
100	350	963
50	175	481
25	88	241
15	53	144

Sources – Corn production from ECW (2005), ethanol production assumes 2.75 gallons/BU.

Biodiesel

The growth of biodiesel in the U.S. is more recent and serious promotion for its production and usage began around the year 2000. In the year 2004 about 30 million gallons were produced growing rapidly from 2 million gallons in the year 2000. Currently, there are about 30 biodiesel production facilities (many of them small) scattered in many states. Some of the larger ones are located in Iowa, Texas and California (NBB, 2005). Recently Cargill announced that they will build a 37.5 million gallon facility in Iowa with production commencing in 2006 (Cargill, 2005). The 2005 Energy Bill includes subsidies for biodiesel production of $1.00 per gallon. Biodiesel is expected to grow rapidly, with rates as high as 100 % for the next few years. In Table 7 we summarize distillate fuel use and the potential for soybeans to produce biodiesel for the Wisconsin market.

Soybean oil is the primary crop in the U.S. that provides protein feed and oil. A small fraction of this oil is now going to the biodiesel production. B2, a 2 % blend is used to increase lubricity. A standard B20 (20 %) blend does not require vehicle modification and has become very popular (Tyson, 2001). Wisconsin could meet a B2 requirement using soybeans only from the high density counties (Table 7).

Table 7: Distillate fuel use and potential for biodiesel to meet demand

Distillate fuel (million gallons/year)	Soybeans (million BU/year)	
1300		Total distillate fuel use
26		B2 biodiesel mandate
130		B10 biodiesel mandate
76	54	Total soybean production and conversion to biodiesel
26	18	Soybean production (counties >3000 BU/sq mile) converted to biodiesel

Sources – Distillate fuel use from EIA (2005), soybean production from ECW (2005), conversion efficiency for soybeans to biodiesel = 1.4 gallons/BU from Campbell (2005).

Organic acids

Acetic acid is a 16 billion pound product that almost entirely produced from natural gas via a catalytic route. Acetic acid could be produced by carbohydrate or syngas fermentation (Gaddy 2004, Snyder 2005b, Heiskanen, 2004).

Lactic acid and derivatives have received significant press recently. This is primarily driven by two derivative products the PLA biopolymers and biosolvents and solvent blends (acetates, lactates, or Vertec Biosolvent's solvent blends, 2005).

In comparison to ethanol, acetic and lactic acid have a distinct advantage. To maintain electron balances, theoretical yield for ethanol production from sugar (or syngas) is about 50 % based on feedstock mass. Theoretical yields for acetic acid and lactic acid are about 100 % based on feedstock mass. Therefore, these acids provide a potential higher product yield.

Other organic acids such as succinic or 3-hydroxy propionic have been identified has potential large volume platform chemicals (Werpy, 2004), but the have neither the markets nor technology are available at this time.

Polyols and other chemicals

DuPont is actively developing technology to produce 1,3-propanediol (PDO) for production of fibers based on 3GT. There are several potential applications for sorbitol (Werpy, 2004). Glycerin, the co-product of biodiesel is a large volume materials used in the personal care products industry, and could be a feedstock for several new products and uses.

In 2004, the DOE Office of Biomass Programs conducted an analysis of the Top Platform Chemicals that could be produced from biomass to replace platform petrochemicals (see Table 8, Werpy, 2004). Most of these products are organic acids or polyols. The report identifies the good potential candidates for R&D investments that could provide the next generation of biobased chemicals used in an integrated biorefinery. ECW (2005) has completed a comprehensive study of biobased fuel and chemical products and we do not have to repeat them here.

In comparison to fossil-based products, biobased products require more distinct, and potentially more costs product separations and recovery strategies. These differences are based on recovery of biobased products from dilute aqueous solutions, and the need to manage pH while producing acids as products or co-products (Hestekin, 2002).

Table 8: Top 12 candidate platform chemicals from biomass

Four carbon 1,4-diacids (succinic, fumaric, and malic)
2,5 Furan dicarboxylic acid (FDCA)
3-Hydroxy propionic acid (3-HPA)
Aspartic acid
Glucaric acid
Glutamic acid
Itaconic acid
3-Hydroxybutyrolactone
Glycerol (glycerin)
Sorbitol (alcohol sugar of glucose)
Xylitol/arabinitol (sugar alcohols from xylose and arabinose)

Source: Werpy (2004)

Synergies

One of the strategic issue and question that often arises when discussing the biobased chemicals vs. already entrenched petrochemical is the relative production plant size. This is a complex issue and detailed discussion and specific economic factors are beyond the scope of the report. However, some important general factors come into play. For biobased chemicals: feedstocks cost is often 50 to 70% of the products cost. If that is competitive with petrochemical feedstock then the production plant size does not have to be very large. Thus for example: the ethanol from dry mill is competitive with the wet mill at a much smaller production volumes (at 25-50 million gallons/year compared to 100-200 million gallons/year). Moreover ethanol is now competitive with gasoline at current crude oil prices without subsidies despite the fact the petroleum refineries are two orders of magnitude larger than ethanol plants.

In the next section we have highlighted some of the technologies and integrations that will be critical to consider and develop for making Wisconsin become competitive in future of the biobased products industry.

Technologies

There are three distinct technological paths to convert biobased feedstocks to fungible products.

1. Conversion to fermentable sugars followed by fermentation
2. Gasification to syngas and either use of the syngas as a fuel or conversion by catalysis or fermentation
3. Transesterification of fats and oil to biodiesel (alkyl esters) and recovery of the glycerin co-product.

1. Fermentable sugars/Fermentation

Wet milling and dry grind milling are the two major processes use to produce bioethanol from corn. Wisconsin has several dry grind mills in operation or planning (Table 9). The capital costs and infrastructure needs for dry milling are much lower than wet mills.

Table 9 Ethanol plants in Wisconsin

Ethanol Plant	Location	Capacity (million gallons/year)	Comment
ACE Ethanol	Stanley	39	
Badger State Ethanol LLC	Monroe	48	
Central Wisconsin Alcohol	Plover	4	
United WI Grain Producers	Friesland	49	
Utica Energy LLC	Oshkosh	48	
Western Wisconsin Renewable	Boyceville	40	under construction

Source Ethanol RFA (2005)

In dry mills, dextrose is readily fermented by yeasts to ethanol. The theoretical yield for dextrose (sugar) to ethanol is 51% (Eq. 1) and typically 95 % of this theoretical yield is achieved in a well run and optimized plant.

$$C_6H_{12}O_6 \rightarrow 2\ C_2H_5OH + 2\ CO_2 \qquad (1)$$

Production of CO_2 is required to maintain the electron balance of the reaction.

Dry milling technology is simpler than wet milling and amenable to smaller scale plants (Figure 2). Corn is ground, slurried and hydrolyzed (at temperature of 90 to 100 °C) with thermostable alpha-amylase enzyme. This mash is then cooled and fed to fermentors with the addition of glucoamylase enzymes and yeast. The fermentations are run in non-sterile conditions at low of pH around 3 to control bacterial contamination and are usually run as batch fermentation with some yeast recycle. Typical ethanol concentrations of 8 to 10% (v/v) with 95% of the theoretical yields (~2.75 U.S. gallons per bushel) are readily achieved and typical fermentation time range between 30 to 40 hrs. This fermented "beer" is directly distilled and azeotropic ethanol is produced overhead which is further converted to anhydrous ethanol by molecular sieve or pervaporation technology. The bottoms now contain all the unfermentables: corn fiber, germ, oil, protein and the yeast. This is usually centrifuged. The liquid fraction (stillage) is recycled to the fermentor and the solids fraction is usually further mechanically pressed to recover more water to make wet distillers grains and solubles (wet DDGS) or dried further to make dry DDGS. The handling, infrastructure and sale of the DDGS have been some of the important issues for the viability and economics of the dry milling technology. Wet DDGS cannot be stored and need to be consumed as animal feed within a short time. Thus, many of the smaller dry mill plants need and have local farmers and farm cooperatives that are financially committed to the ethanol plant, corn supply and the purchase and use of the wet DDGS. More recently, the larger farm cooperatives and agricultural enterprises have invested in standardizing and promoting DDGS use. Recently the dry milling ethanol enterprises are being consolidated and larger plants that produce dry DDGS are emerging. However, the solids handling drying for the DDGS are often the largest component of the equipment capital and energy consumption and the “DDGS issues” will continue to be very important to the dry mill technology. Typical dry mills produce about 25 – 50 million gallons of ethanol per year and capital costs are in the range of $1 per gallon of capacity.

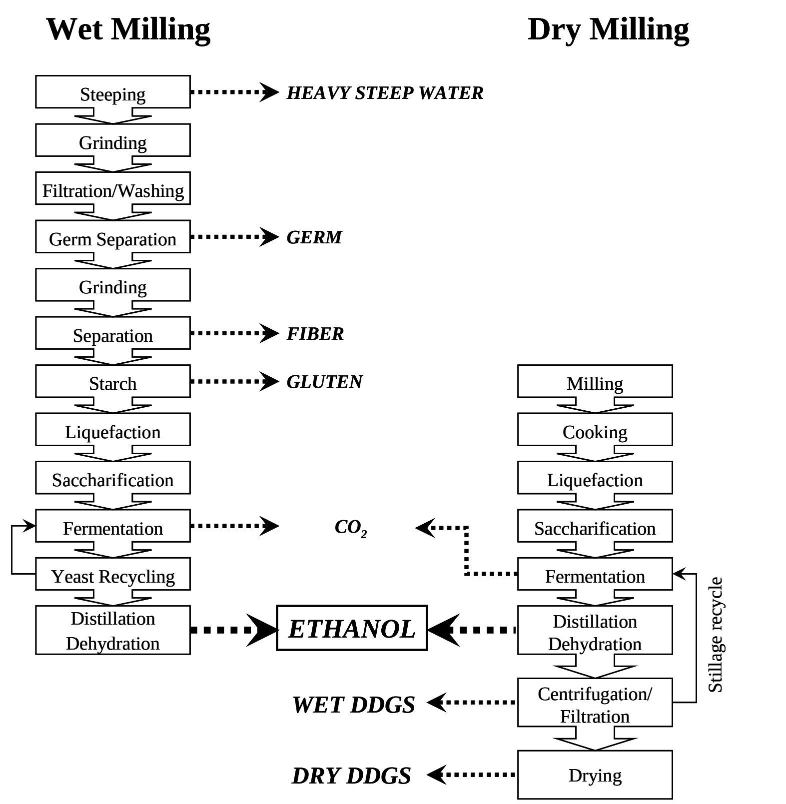

Figure 2 Comparison of corn wet and dry mill processes

Synergies between dry mills and distiller grains

Wisconsin has enormous advantages in the supply chain because of the close proximity of the high density corn industry and the dairy industry. The centers of these industries are only about 100 miles apart. This enables partnering and developing a supply chain for WDGS. By avoiding the costs and energy required for drying the wet DDGS to produce dry DDGS, Wisconsin dry mills will have a competitive advantage over other Midwestern corn producing states. Concerns regarding use of wet distiller grains have been addressed:

> *The main considerations between the use of wet versus dried CDG are handling and costs. Dried products can be stored for extended periods of time, can be shipped greater distances more economically and conveniently than wet CDG, and can be easily blended with other dietary ingredients. However, feeding wet CDG avoids the costs of drying the product (Schingoethe, 2001)*

In terms of volume, ethanol as a liquid fuel business is about tenfold larger than potential of the chemical products. Thus building a base from corn conversion and developing the synergy with the dairy feed is a very important part of the strategy for building a biobased chemicals industry. Once this base begins to be built, the chemicals that have significant growth potential can be added on to the existing production plants or plants can be converted to the production of these chemicals.

Examples of additional chemicals that could be produced from the fermentable carbohydrate include all of the potential bioproducts that were discussed earlier. These are: organic acids and their derivatives (acetic, lactic, succinic, 3-hydroxy propionic); polyols such as 1,3-propanediol and other platform chemicals. For each of these chemicals, the fermentation strains and recovery processes would be different and those are being developed by the current manufacturers of the products. However, note that fermentable feedstock cost would be >50% of the cost of production of these chemicals and the competitive feedstock cost position is an important factor is decision making for locating manufacturing plants.

2. Gasification and conversion of syngas to fuels and products

Gasification is the preferential route with higher lignin content biomass and biomass-derived feedstocks. Wood, residues and black liquor from forest product processing are the primary feedstocks that fit this category.

Gasification and P&P mills

Wood gasification has been developed and widely practiced over the past century particularly before WWII, in Canada, U.S. and Europe. The scale of operations have ranged from small portable gasifiers to run engines to mid-sized gasifiers to run heat and power for wood processing plants, paper mills etc. (Goldman, 1939). Thermal efficiencies of 70-80% have been readily achieved when dried wood or densified biomass with 20% moisture were used. More recent work with biomass gasification with bagasse has been reported (Macedo, 2004). Generally, gasification of wood or densified biomass with low to moderate moisture content (20 to 30%) gives good thermal efficiency to readily produce a mixed gas composed of CO, H_2, CO_2, H_2O vapor with small amounts of CH_4 and tar and some ammonia and sulfides (100 to 1000 PPM).

In chemical pulping, the cellulose is separated from the hemicellulose and lignin. The cellulose is used to produce paper and other products. The separated hemicellulose and lignin is recovered as a solution called spent or black liquor that also contains the spent chemicals (sodium carbonate and sodium sulfide or sulfite) (Wag, 1997). It is essential that the energy content and chemicals of the spent liquor be recovered. The Tomlinson technology is over 80 years old and a significant fraction of the recovery boilers in the U.S. are reaching the end of their service life.

There is intense interest in having improved black liquor processing technology commercially available in the 5 – 10 year timeframe (Larson 2003). The P&P industry has identified significant benefits to replacing recovery boilers with gasification systems. These include significantly increased power production efficiencies, ability to increase yields with advanced pulping chemistries made possible by gasification, flexibility to process biomass and other mill waste streams, and the flexibility to produce other biobased chemicals and fuels. There are two leading BL gasification processes: ThermoChem Recovery International uses a low temperature, indirectly-heated fluidized bed steam reforming technology to gasify organic feedstocks (TRI, 2005a). Chemrec (Sweden), the other major BLG provider, uses a high temperature partial oxidation processes that uses an air-blown, circulating fluidized bed gasifier (Berglin, 2003, Chemrec, 2005). TRI is completing a commercial demonstration with Georgia Pacific at Big Island, VA, and Chemrec is completing a commercial demonstration with Weyerhaeuser at New Bern, NC (Chemrec 2002, TRI, 2005b, Larson, 2003).

The black liquor solids (BLS) contain about half of the energy of the wood feedstock (Larson 2003). The BLS is burned in the boilers to recover the sulfur and sodium pulping chemicals for recycle, and provides all of the process steam, and some of the power for the P&P mill (Larson 2003).

The TRI process produces a syngas with a mixed composition of H_2, CO, CO_2, H_2O, NH_3, H_2S, etc. In the steam reformer system, the H_2S in the product syngas is recovered by amine scrubbing prior to use as a fuel gas. Current sulfur recovery technologies add significantly to the total capital and operating costs of the system. Reducing capital and operating costs will significantly increase conversion to gasification in P&P mills. One advantage of starting with black liquor is that the feedstock is already available at the P&P mill. Avoiding the need to develop the infrastructure for biomass collection increases the likelihood of commercialization.

The state energy authority has conducted an impressive analysis of the advances in the BLG and wood gasification technologies (ECW, 2005).

Taking a typical mill size of 3000 MT of black liquor solids (BLS) and a reasonable conversion of 100 gallons ethanol/dry ton BLS, a P&P mill could produce about 100 million gallons of ethanol per year. The P&P ethanol production falls between the size of a dry and a wet corn mill. Therefore, the fuel output of the P&P mill will be well matched with the existing industry. Conversion of a 100 Kraft mills to ethanol producers would yield 10 billion gallons of ethanol/year, more than twice the size of the current U.S. bioethanol production. Organic acids such as acetic and other alcohols such as butanol could also be made from syngas.

Given Wisconsin's preeminent position in P&P and other forest products this product and technology path would be very important for its long term competitiveness in the biobased chemicals industry.

Fuels and chemicals from syngas

Syngas, a mixture of CO, H_2/CO_2 and other smaller components can be derived from any carbonaceous feedstock – coal, natural gas, petroleum residues and biomass by a wide range of gasification technologies. Extensive R&D a well as commercialization of syngas from coal, natural gas and petroleum residues to liquid fuels have occurred over the past 80 years. The three products that are relevant from the biobased chemicals view point are: Fischer – Tropsch liquids, mixed higher alcohols via catalytic technology or ethanol and organic acids by fermentation and bioprocessing. Due to the diffused nature of growth and collection, biomass feedstocks cannot be procured and processed in very large sized plants (typical size is 1000 - 3000 MT/day). Due to the heterogeneous nature, the feedstocks will contain proteins and sulfur and the raw syngas will contain sulfides, ammonia and other impurities. Therefore, important factors for technical and economic relevance and competitiveness are: a) gas purity and conditions needed for the conversion, b) optimum size for commercial plants. A recent report has conducted a comprehensive screening analysis of syngas conversion technologies with special emphasis on the potential for biomass-derived syngas (Spath, 2003).

Chemical/catalytic technologies

Fischer-Tropsch liquids

Liquid fuels from coal derived syngas by Fischer Tropsch (FT) process was developed and used by Germany in WWII and recently South Africa which produced 13 billion pounds in 2002. These liquid fuels are long chain hydrocarbons that could be used as diesel or heavy duty engine fuel. Biomass derived syngas was never considered or utilized for these large scale plants.

The general process flow diagram is presented elsewhere (Spath, 2003). There are four main steps – syngas generation, gas purification, FT synthesis and product upgrading. The syngas generation conditions depend on the feedstock, usually it is high temperature gasification in presence of oxygen and steam. The gas cleanup requires the steps of particulate removal, wet scrubbing, catalytic tar conversion, sulfur removal via amine scrubbing type of processes etc. The impurity tolerance of FT synthesis gas is very strict: sulfur – (60 ppb to 200 ppb), nitrogen - (10 ppm NH_3, 200 ppb NO_x, and 10 ppb HCN), halides - (10 ppb) (Boerrigter, 2002, Dry, 2002).

Depending on the type or quantities of products desired either low (200-240 °C, 7-12 bar pressure) or high temperature (300-350 °C, 10 to 40 bar pressure) synthesis is used with either iron based or cobalt based catalyst. The reactions are very exothermic and variety of reactor types and geometries has been used. The low temperature synthesis produces linear hydrocarbons and waxes which can be further cracked and processed to make diesel type liquid fuels. The high temperature synthesis produces more of the unsaturated olefinic products, which can be further processed by oligomerization, isomerization and hydrogenation to gasoline type liquid fuels.

From biomass conversion viewpoint the FT technology and products have very significant impediments. Oxygen or oxygen enriched air is required. The raw gas has to be cleaned to stringent standards, and pressurized. The reactions are exothermic and intermediates are produced that have to be further converted to the desired fuels. A wide variety of byproducts are produced and they have to be sold as specialty products to make the operation profitable. For example, the SASOL plant sells about 200 specialty co-products while providing the primary liquid fuels from its large operations. And most significantly, due to the complexity of the operations, the FT technology works at very large scale (10 – 20 million pounds/day or higher) which is conducive to fossil-derived feedstocks not biomass (Bain, 2005; Spath 2003)

Mixed alcohols

Methanol is produced worldwide from syngas by well-developed catalytic processes, and currently ~90 billion pounds are produced worldwide, primarily from natural gas. In the past, i.e. late 19th and early 20th century, methanol was produced from biomass by wood distillation and later by syngas from wood gasifiers. These are not likely to come back and become competitive. Furthermore, because of its phase behavior and other properties methanol is not compatible as a supplement to gasoline or diesel fuel. Thus the large usage of methanol as a liquid fuel would require a separate infrastructure for internal combustion engines and fuel supply and this not likely to happen soon.

Other alcohols such as ethanol or a mix of higher alcohols can potentially be derived from syngas, either by biocatalytic process or by catalytic process technology. Mixed alcohols are more attractive and amenable to gasoline blending stock than methanol, because of higher vapor pressures, phase behavior and octane numbers. There are several avenues for the development of the technology and two – modified methanol synthesis or modified Fischer-Tropsch technologies are being pursued. Depending on the process conditions and catalysts used, the most abundant products are methanol, CO and CO_2, which then undergo higher alcohol synthesis by CO insertion to form C-C bonds and further homologation and hydrogenation. The product mixture contains primarily ethanol followed by smaller fractions of propanol, butanol etc. The yield and selectivities are low. The typical process conditions range between 250 to 350 °C, 50 to 250 bar pressure (Spath, 2003). The reactions are exothermic and reactor geometries similar to the FT technology are needed. The gas conditioning and clean up requirements are similar to that of methanol and Fischer-Tropsch technologies, except for one of the catalyst developed by Dow Chemical Co. in the 1980s, which uses molybdenum sulfide and is therefore sulfur tolerant, but its nitrogen tolerance is unknown (Herman, 2000).

Unlike FT technology, there are no commercial plants to produce mixed higher alcohols for liquid fuels and the products have not been approved for gasoline blending (Lucero, 2004, Spath 2003). From a biomass conversion viewpoint this technology has technical and size incompatibility impediments similar to that of the FT technology (Bain, 2005).

Fermentation/bioprocessing technologies

In Figure 3, a schematic process for fermentation of BLG syngas to ethanol is presented. Several organisms are known to produce ethanol from syngas including Clostridium ljungdahlii (Gaddy 1992). Other organisms such as *Acetobacterium woodii*, *Clostridium thermoaceticum* are known to produce acetate from syngas. There are particular advantages to BLG syngas fermentations and potential technical barriers summarized elsewhere (Snyder, 2005a). The two most notable advantages are 1) the volume of feedstock available to P&P mills is much more suitable to fermentation than chemical conversion and 2) microbial strains could be adapted to crude syngas much more readily than chemical catalysts. In Table 10 we estimate production of ethanol in Wisconsin's existing P&P mills by BLG fermentation.

This estimate of 168 million gallons/year of ethanol only includes BLG feedstocks that are already collected and available for conversion. Looking forward, the larger forest product residues and P&P mill residues as an available feedstock of about 3 – 4 million tons/year could be used to produce an additional 300 – 400 million gallons/year of ethanol. Please note that this level of production is from residues that do not displace the existing fungible forest products. Direct production of forest products for fuels and chemicals production could be substantially larger.

The significant opportunities and challenges of producing fuels and products from syngas are:

- Significant quantities of biomass derived syngas could become available from the implementation of BLG in Wisconsin, which is beginning in the P&P industries.
- Fischer-Tropsch or mixed alcohol and derivatives technologies that are being developed are more suitable for syngas derived from fossil sources such as coal or remote natural gas, than biomass feedstocks. This is because the amounts of biomass syngas do not meet the economies of scale of these chemical processes.
- Ethanol and acetic acid by anaerobic bioconversion of crude syngas is an emerging technology that has a very significant potential to be compatible with biomass feedstocks and also produce ethanol at prices less than $0.75 per gallon.
- Further development of this technology would require – organism/strain development, bioreactor design and development and integration with advanced separations technologies.

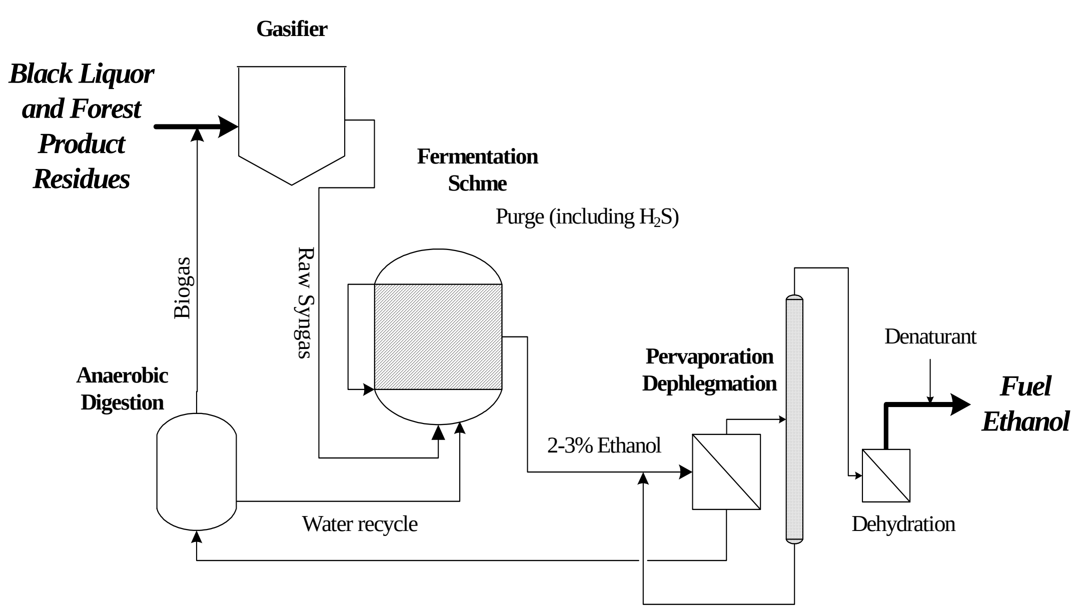

Figure 3: A schematic process for fermentation of BLG syngas to ethanol

Table 10: Black Liquor Gasification to ethanol potential

Kraft Mill Name	City	Pulping Capacity (tons/year)	Ethanol (million gallons/year)
Thilmany (formerly IP)	Kaukauna	203,000	32.1
Stora Enso N.A. -Pulp Mill	Wisconsin Rapids	658,000	103.9
Domtar Industries (GP)	Nekoosa	108,000	17.1
Wausau-Mosinee	Mosinee	96,000	15.2
Totals		**1,065,000**	**168.2**

BLG notes: Only mills with Kraft (sulfate) chemical pulping are candidates for BLG. Chemical pulping capacity (which may be less than paper making capacity) is used for this table. Sources: Kraft mills data from ECW (2005), BLG available per ton of pulping capacity available from Larson 2003, conversion of BLG to ethanol from: Snyder (2005a).

3. Transesterification

Biodiesel is the methyl ester of fatty acids derived by transesterification of fat or vegetable oil which are fatty acid triglycerides. The biodiesel production process has been described elsewhere. The reaction is simple transesterification with base or acid catalyst. The methanol is in excess in the reactor, the reacted phases separate and the methyl ester/methanol phase is washed, purified and the excess methanol is evaporated and recycled. Currently 95 % of the theoretical yield is achieved with this process. The oil feedstock is the largest cost factor in the production process. For example, in the soybean oil accounts for close to 90 % of the production costs (Hamilton, 2004)

The glycerin phase is neutralized, the residual methanol is evaporated and recycled and the crude glycerin with some of the residual fatty acid is the main byproduct. This has to be further purified to produce a fungible co-product of industrial grade glycerin, or the crude product has to have a useful outlet. As the production and usage of biodiesel increases this co-product glycerin issue will become increasingly important. Purified glycerin is sells for $0.50-075 per pound in the consumer products markets. If biodiesel grows rapidly and the glycerin is purified, this price could decline sharply, and there could be serious market disruptions.

For example, if the biodiesel production increases as envisaged, to 3 billion gallons, about 2 billion pounds of crude glycerin will be produced. This will approach or exceed the refined glycerin production of the oleochemical industries for consumer products. Thus just making refined glycerin from the crude is not going to be a viable option. Current glycerin producers are investigating replacement of other glycols such as ethylene and propylene glycols in their existing applications, which may be difficult to penetrate. Additional opportunities where there is a potential for growth could be based on bioconversion technologies. These are representative large volume opportunities:

- Fermentation to ethanol for biofuels.
- Bioconversion to 1,3-propanediol for emerging DuPont's 3GT polymers.
- Carbon source for fermentation feedstock to supplement dextrose syrups.

Conclusions and Recommendations

1. Wisconsin is a mixed agriculture state but unlike its agricultural Midwestern neighbors, it also has a preeminent forest products industry.
2. Three feedstocks: corn, forest products (pulp and paper and forest residues) and soybeans are the only ones appropriate for building a biobased chemicals industry over the next decade.
3. During the past few years biobased liquid fuel products namely: ethanol and biodiesel (fatty acid methyl esters) have been the base drivers for the growth of the industry. In terms of volume the liquid fuel business is about tenfold larger than the chemical products. Thus building a base for these fuels from conversion of the state's competitive resources is a very important part of the strategy for building a biobased chemicals industry.
4. For corn, dry milling technology should be primary path. The potential synergy between the state's dairy industry's feed needs and the wet DDGs from the dry mills should be actively developed and exploited. This synergy can differentiate Wisconsin from the other mid-western corn growing states and make it very competitive.
5. The initial growth product should be fuel ethanol (the state already has about 200 million gallons/year production) followed by opportunistic addition of other biobased chemicals.
6. Organic acids namely: acetic, lactic and its derivatives (PLA and solvents) and polyols (1,3 propanediol) would be some of the prime targets.
7. Biodiesel from soybean oil has a strong growth potential. For Wisconsin, developing a synergy between the state's dairy feed needs and the soybean meal and developing use for byproduct glycerol would be important to make it competitive.
8. Gasification is the preferential route with higher lignin content biomass and biomass-derived feedstocks. Wood, residues and black liquor from forest product processing are the primary feedstocks that fit this category.
9. Syngas fermentation/bioprocessing technologies to make ethanol and organic acids such as acetic acid is the recommended technology path and given Wisconsin's preeminent position in P&P and other forest products this product and technology path would be very important for its long term competitiveness in the bio based chemicals industry.
10. In order to develop a biobased chemical industry, Wisconsin will need to identify and partner with end users. Advantages to consider in the future include carbon dioxide credits to meet Kyoto Accords for European based companies.
11. Wisconsin has a strong academic and National Laboratory sectors. Many of the technologies require a skilled workforce. Fostering of R&D and training programs in the relevant technologies will help provide the workforce for the biobased industry. In addition, a strong R&D presence will help Wisconsin develop higher-valued specialty products.

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TECHNOLOGY/EXPERTISE

- Science and technology program development in chemistry, biochemistry, chemical engineering, biotechnology, and nanotechnology.
- Development of conversion systems for production of platform chemicals.

PROFESSIONAL EXPERIENCE

2001-: ARGONNE NATIONAL LABORATORY, Argonne IL, Section Leader – Biochemical Engineer, Energy Systems, Chemical and Biological Technology Section

- DOE Office of Biomass Programs – Lab Relationship Manager
- Council of Chemical Research – Argonne Representative, Co-chair Research Collaboration
- Institute for Genomics Biology, University of Illinois Urbana Champaign – Affiliate
- R&D100 winner – 2002 "Advanced Electrodeionization for Product Desalting"

1998-2001: ARGONNE NATIONAL LABORATORY, Associate Director, Chemistry Division

1994-98: ABBOTT LABORATORIES, Abbott Park IL, Senior Research Biochemist, Protein Biochemistry

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EDUCATION

UNIVERSITY OF VIRGINIA: Ph.D. in Biophysics, 1990 & M.S. in Physical Chemistry 1985
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35+ publications in chemistry, biochemistry, and chemical engineering
5 patent Applications in processing and separations

SELECTED PROFESSIONAL ACTIVITIES (SINCE 2002)

- Organizing Committee – North American Membrane Society Annual Meeting –2006
- Organizing Committee – Biotechnology Industry Organization (BIO) Annual Meeting – Industrial and Environmental Section – 2006
- Session Chair – 28th Symposium on Biotechnology for Fuels and Chemicals – 2006
- Invited Plenary Speaker – iBIO – "The Future of Biofuels" – 2005

- Invited Speaker – ENERGY STAR® Energy Efficiency in Corn Refining" ANL Membrane Separations Technology and the Biofuels Initiative" – 2005
- Invited Speaker – University & Industrial Consortium – "Bioprocessing R&D Needs to Achieve Energy Independence" – 2005.
- Co-author for biomass and technical editor for renewables for a SRI-type industry report on "Alternative Energy and Fuels Technology" for The Catalyst Group Resources
- DOE Office of Biomass Programs – Lab Relationship Manager – 2004 -
- Division Representative – Chemical Engineering Study Group (strategic advisory group) – 2004
- Plenary Session Chair – The Biobased Economy – Council for Chemical Research annual meeting– 2004
- Panelist – Infocast – Nanobiotech Intellectual Property Landscape – 2003
- Invited Speaker – AIChE Annual Meeting - Separations Panel –2002
- Invited Speaker – Twentieth Annual Membrane/Separations Technology Planning Conference –2002
- Coordinated technical capabilities study for the Midwest Consortium for Biobased Products for DOE – Office of Industrial Technologies – 2002
- Directed technology assessment for direct capture of products from biotransformations for DOE – Office of Industrial Technologies – Vision2020 Separations Panel – 2002
- R&D100 winner "Advanced Electrodeionization for Product Desalting" – 2002

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- Bioprocess, Fermentation and Separations technologies.
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VERTEC BIOSOLVENTS, Inc. Dowers Grove, Illinois **Founder and Chairman,** 2000 -

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2002 R&D 100 Award – Advanced Electrodeionization Technology for Product Desalting, Argonne National Laboratory and EDSEP, Inc.
1998 Discover Magazine Award for Technology Innovation — Membrane-Based Process for Producing Lactate Esters.
1998 President's Green Chemistry Award — Novel Membrane-Based Process for Producing Lactate Esters – Nontoxic Replacements or Halogenated and Toxic Solvents.
1996 Recipient of the AIChE's Ernest W. Thiele Award.
1970 Director's Medal, 1st Place in Chemical Engineering.

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Member, Research Evaluation Committee, National Corn Grower's Association, 1990-93.
Editorial Board, *Journal of Industrial Microbiology*, 1985-90.
Editorial Board, *Journal of Chemical and Biochemical Technology JCTB, 2005* --.

PUBLICATIONS AND PATENTS

35+ publications in the areas of fermentation, separation, enzyme catalysis, energy conversion, and process economics;
50+ presentations, seminars, invited lectures, etc.
20 U.S. patents in fermentations, bioproducts, bioprocessing and separations technologies.

Appendix B

Workplan
Wisconsin Biobased Initiative—Chemical Industry Report
November 9, 2005

The deliverable under this workplan is a paper which is intended to be included as part of a larger technical scan outlining ways in which Wisconsin could participate in the biobased economy. The Contractor should consider the following questions to be the issues to be addressed by the paper. The questions are not intended to suggest a structure for the paper, nor are we looking for a numbered list of "answers." The expected length of the document is 13-18 pages and should be sourced. Simple charts, tables, flowcharts, etc. will be reformatted by the Company and should therefore not receive undue attention from the Contractor related to their graphic design.

1. How can Wisconsin, with no significant native chemical industry, gain a foothold in that industry? What advantages might Wisconsin have in entering the biobased chemical industry relative to other states with a similar lack of chemical industry infrastructure? Note: We can provide data regarding Wisconsin's resources, although the short list would be aligned around the following:
    - Forestry & papermaking
    - Production agriculture
    - Beef & dairy
    - Food processing
    - Manufacturing infrastructure
    - Significant intellectual resources at the UW
    - Two national labs (forestry & forage)

2. We are particularly interested in the opportunities for small-scale refineries.
    - What are the opportunities for entering the market with small-scale refineries? Are these different when considering the wholesale vs. the retail market? Commodity vs. speciality? Is the wholesale chemical market substantively different from that for processed or partially refined biomass?
    - In what ways do large-scale and small-scale refineries compete? In what ways do large-scale and small-scale refineries cooperate or exist symbiotically?
    - Let's say you can make biobased commodity chemicals at a competitive cost. One argument might be that this is foolish because petrochemical refineries make a sufficient variety of products such that they could undercut your price for that chemical and threaten your business's viability while not losing much money themselves (the loss leader model). Another argument is that because they make so many

chemicals, they have no real interest in competing on price and would just focus on their other products.

  - Is either of these viewpoints accurate?
  - What other arguments warrant consideration?

3. One opportunity we recognize is just-in-time production of a chemical paired with the consumer of that chemical (e.g., providing hydrogen peroxide to a paper mill, thereby alleviating the need for storage). Apart from those opportunities, and all research being equal:
   - How do you decide what to make?
   - If one was going to create a Top 12 list of chemicals to be made in Wisconsin, what criteria should be used to assess them?
   - Would that list or those criteria be different if Wisconsin were to focus on small-scale refineries? Large-scale refineries?
   - Suppose a Wisconsin company could supply 10% of the PLA needed by a specific plastics manufacturer at a competitive cost. What would encourage that manufacturer to buy the Wisconsin plastic? Is the manufacturer likely to have an exclusive supplier contract or some similar barrier?

4. If we're trying to get our existing industry clusters (listed above and also including plastics, printing, metalcasting and manufacturing [including vehicles, industrial controls and biomedical]) to adopt biobased chemicals, what needs to be done?
   - What policies work to encourage such purchasing?
   - What are the barriers that hinder industry adoption of biobased chemicals?
   - How does one address those barriers technically? How does one address them from a marketing standpoint? (e.g. Do you need the "authority" of a major chemical company to be considered reliable?)

5. Which of the critical R&D barriers for biobased chemicals might best be addressed by research universities?
   - Are there any cases where a university is doing or has done a commendable job in assisting the chemical industry in overcoming significant hurdles? Are there recommended models for this kind of interaction?
   - Is there a perception in the industry of a specific area that is ripe for additional attention (i.e. a "corridor" for enzymes or manure research)?

6. Under what conditions does refinery proximity to feedstocks matter? Under what conditions does refinery proximity to consumers matter? What are the other considerations related to refinery location? Areas for consideration:
   - Opportunities to tie a product and service together
   - Customers seeking diversification for the sake of risk management

- Transportation costs—truly a factor for commodity chemicals (or commodity feedstocks) that are, by definition, fungible?

7. Consider these components of the chemical industry:
    - the feedstocks from which the chemicals are derived
    - the physical location at which the refining takes place & its installed capacity
    - the patents governing that refining
    - the professional and intellectual capital associated with running a refinery
    - the consumers of or markets for the chemicals
        - Which components are missing from that list?
        - Which deliver the most value?
        - Is it worthwhile (for the state as whole) to provide only one of those components?
        - Is it feasible to be provide all of those components?

8. Which questions would you have answered differently if they said “enzymes” instead of “chemicals,” and why? What about “nutraceuticals?” Are there other classes of product that fall outside the traditional “chemicals” rubric that might be accommodated by this infrastructure?

Appendix C

State-level data

We investigated several sources for feedstock and channel data. These included:

- Licensing data from Wisconsin Department of Agriculture, Trade and Consumer Protection
- Wisconsin Agriculture Statistics Service
- Wisconsin Department of Natural Resources
- US Department of Energy

Interviews

We interviewed players with interests in every level of the bioeconomy as a research tool to understand their ideas and concerns about the development of biobased industry. Our interviewees included:

- Rob Anex, Iowa State University
- Eric Apfelbach, Virent Energy Systems
- Sandra Austin-Phillips, UW-Madison
- George Berken, Boldt Construction
- Jeff Boeder, City of Milwaukee
- Cory Brickl, GHD, Inc.
- Dick Burgess, UW-Madison McArdle Laboratory for Cancer Research
- Bill Clingan, Wisconsin Department of Workforce Development
- Laura Dresser, Jobs With a Future
- Wendel Dreve, Harrison Ethanol
- Don Erbach, USDA
- Steve Hansen, Cashton Area Development Corporation
- Colin High, Resource Assistance Group
- Bill Holmberg, Biomass Coordinating Council
- Jim Kleinschmitt, Institute for Agriculture and Trade Policy
- Larry Krom, Focus on Energy
- Arlen Leholm, UW Extension
- Phillip Lusk, Resource Development Associates
- John Malchine, Badger State Ethanol
- James Martin, Omnitech International
- Mark McCalsin, Forage Genetics International
- Wisconsin State Representative Al Ott
- Michael Pacheco, NREL National Bioenergy Center
- Chris Peterson, Michigan State University Product Center for Agriculture and Natural Resources
- David Pimentel, Cornell University
- Brad Rikker, Wisconsin Alumni Research Foundations
- Niel Ritchie, League of Rural Voters

- Alan Rudie, USDA Forest Products Laboratory
- Mike Spahn, Anamax Grease Services
- James Surfus, Miller Brewing Co.
- Michael Sussman, UW-Madison Biotechnology Center
- Egon Terplan, ICF Consulting
- Ben Thorpe, Agenda 2020
- Greg Wise, UW Extension
- Daniel Zitomer, Marquette University